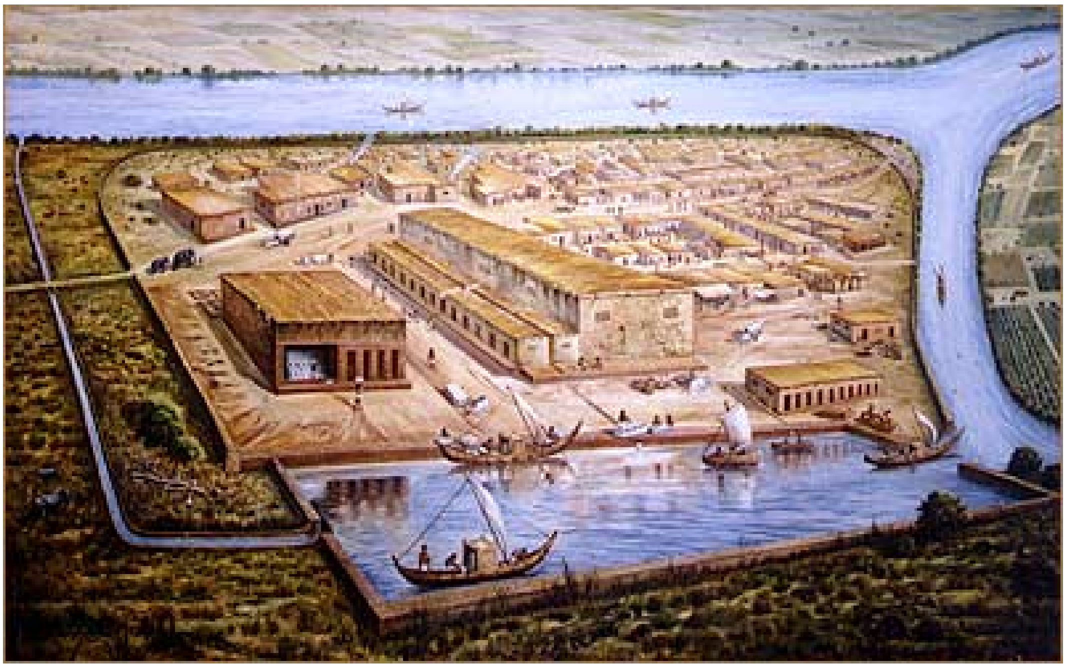
Predictive Modelling of Harappan Port Sites in the Gujarat



Lothal as Envisaged by the Archaeological Survey of India

Roy Mathur MSc

Submitted for the Qualification of PhD

University of York, Department of Archaeology, United Kingdom

August 2009

Dedication

This work is dedicated to my family: Roy Mathur Senior, Premjyotee Ramowtee Mathur and Bruno Mathur.

Addendum and Errata

Abstract

"It is the aim of this research to test the hypothesis that computer-based predictive modelling can be effective as a site location tool and that these models can also be made more accurate by the inclusion of other factors such as geographical, social, economic and political theory, particularly where there are short-falls in the availability of environmental data traditionally used in such models. The effectiveness of this holistic, polymathematical approach drawing from many disciplines may be judged by its capacity to solve important archaeological questions.

The Harappan Civilisation of the Gujarat in North-West India is a fresh area where predictive modelling can be tested with no pre-conceived notions, rather than in Europe, where the small scale geography and local knowledge tends to mitigate against model use, and then only sparingly in CRM, or the huge expanses of North America where models that can narrow the focus of exploratory ventures are welcomed and widely used.

First, there is a need to properly identify Harappan port city criteria; a contentious issue as, thus far, there has been no consensus of what properly constitutes a Harappan port city, for example, the Lothal controversy.

Secondly, by identifying these sites as well as their involvement in both intracultural and extracultural trade and exchange mechanisms and dynamics, the foundations of the Harappan maritime trade network may be further exposed and interpreted over time.

Thirdly, only a few of these sites have so far been discovered and, thus, there is a high probability that, given the geographical expanse, the area could have supported far more of these sites than have yet been found. Thus, new search areas need to be identified as a first step towards further exploratory archaeology.

Finally, as it has been stated that this is a multi-disciplinary approach drawing on various technological processes, it is necessary where appropriate, to use computer technology to aid in this research. "

Executive Summary

This research attempts to develop a predictive model through the use of various software tools with a view to identifying locational criteria related to possible Harappan age port sites in the Gujarat region of North-West India and thus, assisting in forming a clearer picture of maritime interaction network links both within the Gujarat as well as externally.

The Harappan Civilisation was discovered at around the start of the twentieth century, over the course of time and various excavations, it is now deduced, that, at present, this is probably the largest, in terms of defining geographical extent, of the Old World Civilisations, with possibly the shortest life-span. The main period of development; the Mature or Urban Period spans, very approximately, from 2500 BC to 1900 BC, though aspects of the culture may have began far earlier and end far later.

Unique aspects of the Harappan culture include sophisticated and complex urban planning and social organisation, shared material cultural artefacts, a seeming lack of warfare coupled with the pre-requisites for large-scale trade including pictographic seals, a standardised system of weights and a resource rich ecosystem. Major sites include Harappa and Mohenjo daro in modern Pakistan, Dholavira and smaller sites such as Lothal in the Gujarat, that is thought by some, controversially, to have been a port.

The predictive model developed indicates that most of the port sites are located to the east and that the central area intercepts the important Gujarat Harappan settlement of Dholavira, otherwise settlement patterns are randomly distributed. However, it is thought that new sites may be located around the Sabarmati river near Lothal, the Mahi Sagar river roughly north-east of Kambhat, the Narbada river east of Bhagatrav, the Tapti river east of Surat, the Bhadar river both east and west of Rojdi, the Shetrunji river west of Padri and the coast-line west of Kanakpur.

In terms defining maritime based trading network, given that most of the trade was in an easterly direction, it is thought that goods arrive overland by cart, pack animal or small river-boat from the hinterlands of ports. There, they were sorted and sealed and then sent out by cart to be loaded on to larger sea vessels which navigated by keeping the land to

starboard as they headed out and then north-east across the gulf of Kutch. The ships continued east across the Arabian Sea and then on, perhaps, through the Gulf of Oman and up through the Persian Gulf until they reached Mesopotamia.

Future directions for study might include attempting to build a more generic, multi-period, multi-environment application for site location, the design of an agent based computer model to understand aspects such as trading behaviour, the evolution of cities or the gradual decline of the Harappan Civilisation or attempting to develop a more sophisticated model of port or city evolution from smaller peer polities.

Table of Contents

Tables

Figures

Plates

Cover: Lothal Envisaged by the Archaeological Survey of India, used with the permission of the Archaeological Survey of India and Harappa.com

Accompanying Material

There is an accompanying CD-ROM with this thesis (see Appendix A).

Preface

This thesis is presented to the Department of Archaeology at the University of York.

Acknowledgements

In the United Kingdom: my research supervisor Dr. Penny Spikins, lecturer in prehistory in the Department of Archaeology at the University of York and Dr. Alan Tyler, curator of Bromley Museum (retired).

In Canada: Dr. Jonathan C. Driver, vice-president, academic and provost of Simon Fraser University and Mr. Chi Kin Sham and family of Vancouver.

Also the few Harappan scholars in the United States of America, the United Kingdom and India who were good enough to spare the time to converse with me and all the other people, too numerous to mention, who have assisted me in this endeavour.

Declaration

This thesis is the result of research by Roy Mathur, a post-graduate student in the doctoral programme of the Department of Archaeology at the University of York in the United Kingdom, in partial fulfilment of the requirements for the degree of PhD.

An attempt has been made to scrupulously reference every instance of the work of others, including those found in traditional bound publications, internet websites and even casual oral conversation. If, however, the reader feels that any form of copyright has been infringed in any way whatsoever, they should immediately contact the author at:-

roy.mathur@gmail.com

Introduction

Research Proposal

In this chapter, a broader explanation of the aims, as well as, the philosophical underpinnings of the research proposal, *vis a vis* the abstract, are broken down and examined in detail. Also a justification as to why the Harappan culture of the Gujarat is deemed an appropriate arena within which the research should take place is offered, as well as why predictive modelling presents the most favourable technique to use in the study of this culture. The end of this chapter will consist of a brief examination of current use of technology in archaeology.

Primary Aims and Objectives

From the abstract-

"It is the aim of this research to test the hypothesis that computer-based predictive modelling can be effective as a site location tool and that they can also be made more accurate by the inclusion of other factors such as geographical, social, economic and political theory, particularly where there are short-falls in the availability of environmental data traditionally used in such models. The effectiveness of this holistic, polymathematical approach drawing from many disciplines may be judged by its capacity to solve important archaeological questions."

This is a particularly contentious issue in archaeology, with the science of modelling somewhat limited to its use in, mainly, Cultural Resource Management (CRM) (van Leusen and Kamermans 2005: 7, Podobnikar et al 2000: 535); even its use in CRM has been a controversial topic in the past (Butler 1987: 825). This research makes the case for expanding the reliance on mostly environmental and archaeological data in order to include inferences based on other approaches, such as the use of geographical, social, economic and political theories, not due to any particular philosophical stand-point, rather

because of a requirement to derive more information than is currently available from the mostly environmental data sources (see "Philosophical Context of this Research below").

In order to test the above hypothesis, it is necessary that a predictive model is built and tested in a real world scenario. The arena for testing the model is the Harappan Civilisation as it is expressed in the Gujarat region of North-West India. The Gujarat area of North-West India has been chosen because of the extreme crenelation of the coast-line, its many navigable rivers, inlets, estuaries and its coast projecting deeply into the Arabian Sea offering access to other Old World Civilisations to the west such as Mesopotamia make it ideal as a source of Harappan settlements, harbours, ports and beaching sites, both coastal and further inland. However, only a small quantity of these sites have so far been discovered and, of the many that have been located, very few have been fully researched or surveyed (Lawler 2008) and, thus, there is a high probability that, given the sheer geographical expanse of this region, the area may contain many more of Harappan period port sites.

The Gujarat is also significant because, from this location, the ancient Harappan culture of the Gujarat had access to ample resources of neighbouring areas such as modern Mathya Pradesh and Maharashtra; this enabled the establishment of a large trade network centre (Chakrabarti 2004: 30). This, together with its long coastline and open access, also indicates the strong possibility of maritime routes (Chakrabarti 2004: 29). The Gujarat is also an area that contains many Harappan and Harappan related sites (Chitawala 2004: 90) which are thought to be an extension of Harappan sites in the Sind (Chitawala 2004: 95). There are very large sites such as Dholavira and also sites such as Lothal have been purported to be involved with maritime trade entailing the collection of raw materials from secondary settlements such as Kuntasi, Nageshwar, Nagwada and Shikapur and the dissemination of those materials as goods to the Persian Gulf, Mesopotamia, Sind and Baluchistan (Chitawala 2004: 95) Many of the aforementioned sites have also been, at least tentatively, identified as ports (Rao 1979: 23, Thakker et al 2000: 5, Bhan and Ajithprasad 2008). The Saurashtra coast within the Gujarat is particularly important as it has been identified as the focus of maritime activity within this region and it is where the site of Lothal, amongst others, is located (Gaur and Sundaresh 2005: 44), as well as an area that

shows the Post-Harappan continuity of settlement (Tharpar 1983: 186) and commercialism that lasts and well into recent times (Spodek 1974).

One should also consider the advantage of choosing sample sites which are set within the same or similar landscape as the search area; this avoids bias because features unique to the sample area only are not presented as predicted features in the search area (Kvamme 1990: 379).

Another reason that supports the validity of basing this research in the Gujarat concerns two areas of the world where predictive modelling has been used- Europe and the United States of America. The use of predictive modelling in Europe, for example, in the United Kingdom compared to its use in the United States of America is very different, both in terms of scales and utilisation. The small scale geography of the United Kingdom and the well known location of many sites and potential sites through local knowledge tends to mitigate against its use and then only sparingly in CRM. Whereas within the huge landscapes of North America, any tool that can narrow the focus of exploratory ventures are welcome. Also in North America predictive models are used to assist planners to locate areas requiring less resources to develop from a viewpoint of regulations concerning cultural resources (Mehrer and Wescott 2005: 42), that is, to view the landscape as an economic resource (Mehrer and Wescott 2005: 43) and hence, are not suitable for modelling landscape from the perspective of an interpretive viewpoint (Church et al 2000: 150 to 151). Additionally, in the United States of America, there is also the constraint of government regulation holding back direct prospection (Dix, Quinn and Westley: 2007). Between these two quite different scales of use and, indeed scales of landscape, lies the Gujarat; a fresh area where predictive modelling can be tested with no pre-conceived notions, a region that is also both large in area and also geographically well-contained.

Tackling a lack of conventional archaeological data requires novel techniques. Therefore, this research, in common with landscape archaeology in general, requires a highly polymathematical approach drawing from the work of, possibly, many different, but complementary disciplines such as archaeology, computer science, ecology, geology, ethnography, social theory, geography and data such as archaeological records and reports, satellite remote sensing data, maps, environmental data, ecological data and other sources.

It is hoped that with this holistic approach (Renfrew and Bahn 2005: 141), the most appropriate tools and methodologies are chosen from each discipline on the basis of effectiveness in solving these real-world archaeological questions.

It is also important to emphasise the need for greater archaeological research of this wealthy, sophisticated and the most geographically extensive, yet least researched culture amongst all of the Old World Civilisations. Further, the significance of the Harappans to the history of India is significant in that the development of the Harappan cities marked an early and important phase of urbanisation in India that was not be seen again until the sixth century BC (Himanshu 1987: 94).

It is hoped, therefore, that this research will, at least in some part, help to contribute towards this goal of furthering research into this singular culture. It is hoped that this will be accomplished by suggesting physical locations where further field-based reconnaissance work should be focused and, further, by attempting to solve some controversial issues such as the continued debate over the validity of Lothal as a port site and whether many other sites identified to date are, in fact port sites at all (Thakker et al 2000, Gaur and Vora 1999, Rao 1979). This research into Harappan ports means that one of the products of the research will be a greater understanding of the Harappan maritime trade network; previous research has concentrated on overland routes simply because of the availability of archaeological data.

Secondary Aims and Objectives

Validity of Current Harappan Archaeological Data

Another useful product of the research is that it should enable an opinion to be made on the validity of certain current archaeological data concerning the Harappan Gujarat (see 7.3.6).

Current Use of Technology in Archaeology

Given the high degree of computer use in the research, this is also an opportunity to report on the current use of technology in archaeology and allied fields as well as to also experiment with using this technology to enable a more efficient use of time during the research. For example, with the creation and use of small, time-saving programs, or "scripts" in the modern parlance, that are to be utilised whenever a repetitive manual task can be automated. Copies of these programs can be found in the Appendices (see Appendix A).

Agent Based Modelling

Further to the above point, as an addendum to the major research, it is also proposed to both demonstrate evidence for maritime trade exchanges and to explore the value of decentralised systems modelling by experimenting with agent based programming. This is to be accomplished by simulating trade between Mesopotamia and the Harappans by modelling simple trade rules. The purpose of this is to investigate the value and limitations of agent based modelling to the archaeologist. In fact, this is not a new technique and has been used to simulate population growth and decline in a more sophisticated model for a village of the Anasazi culture in the American South-West (Axtell et al 2002). This minor exercise will assist in confirming the validity of maritime routes for bulk commodity transfer and suggest future directions for research (see 4.5 Trade Simulation, 4.5.3 Harappan Muli-Agent Transport Model and 9.4 Discussion: Multi-Agent Modelling).

Philosophical Context of this Research

Though the tone of the research may sometimes encourage a belief in the reader that a particular philosophical perspective is pervasive, such as descriptive, processural or interpretive; this is not the case.

Processural archaeology (Darvill 2008a) or the New archaeology of 1960s and 1970s America (Darvill 2008b, Renfrew and Bahn 2004: 38 and 39) attempts to utilise systems theory, that is, a holistic view of various interacting sub-systems, to explain change rather than merely describing them (Darvill 2008a), by using modes of thought adopted from other sciences such as biology (Darvill 2008a). Whereas post-processural archaeology or interpretive archaeology explores themes such as power, social change and gender in order to understand human societies (Darvill 2008c).

However, within this research, the paucity of data encourages a certain lateral thinking. Thus, there exists not the comfort of picking between philosophical slants; rather there is the need to pursue, by whatever means necessary, the systems view of new archaeology; particularly those pertaining to computer models (McIntosh 1996), the descriptive methods of traditional archaeology (Darvill 2008a); to obtain a general descriptive overview of culture and typology of artefacts therein (Renfrew and Bahn 2004: 39), the post-processural emphasis on social structures in order to understand possible humanistic motives behind some of the decisions made by the Harappans. All are equally useful points of view in pursuit of the greater goal, which is the pursuit of greater archaeological knowledge and while Taylorian pessimism (McIntosh 1996) is gently refuted, though tentatively acknowledged as a caution against not favouring an objective outlook.

Why is the Harappan Civilisation Useful Arena in Testing Predictive Modelling?

An expansion is now offered as to why the Indus Valley or Harappan Civilisation, henceforth referred to as the Harappan Civilisation in this work with absolutely no political sub-context, is chosen as a testing ground for the model.

It was the largest of the Old World Civilisations yet identified (Kenoyer 1997:3, Possehl 1999: 157, Whitehouse 1977: 121) with achievements of at least equal stature to Mesopotamia and Egypt (Schuldenrein et al 2004: 777). Its recent discovery by western science in the early part of the 19th century means that there is much still to discover about this unique and enigmatic culture. Also despite many years of excavations and much

evidence relating to various aspects of Harappan life, much still remains unknown about the social organisation of the Harappan Civilisation (Jha 1991: 19).

Research has been very sparse when compared to other Old World Civilisations such as Egypt, Mesopotamia and China due to its late discovery, indecipherable script and, as with so much else in archaeology, a lack of available funding. It has largely been the research domain of Indian and American research efforts, in terms of fieldwork at least, since the c.1980s. In addition to this, the culture appears not to have built monumental structures dedicated to any particular king or deity, makes this civilisation appear less interesting as a subject for mass-media exploitation, for example, in television programmes, compared, for instance, to ancient Egypt. Also the geographical inaccessibility of many sites adds to the problem of low exposure of this culture to the public and science in general. ‘Geographical inaccessibility’ is used here to also describe political wrangling between India and Pakistan over some of the areas where these sites are located because a few lie within territorially disputed border regions as well as the difficulty of physical accessibility to some sites and a lack of funding for adequate fieldwork. This debate can most clearly be seen in the more recent Saraswati debacle (Habib 2001: 69).

All these problems, however, are probably due to its only recent discovery by the west; given time, this may change. One must remember that the ancient Egyptian culture is thought to have been already a tourist attraction by the time of the Romans.

For all these reasons, this same general lack of knowledge about the Harappan Civilisation, however, makes the culture an attractive proposition as a research subject compared to the other Old World cultures which already benefit from an admirable, though vast, pool of Egyptologists, Assyriologists and Sinologists. Therefore, any further research that adds to the very gradual growing body of knowledge of what is known about the Harappans is clearly valuable. In fact, during an interview with *Current Anthropology*, after being asked the question about where he would consider additional fieldwork, Colin Renfrew makes the point that he believes that the Indus Valley area is under-resourced in that the number of students and researchers is very small compared to that of the Aegean (Bradley 1993: 76).

The Harappan culture is also gaining importance in the public perception, as well as news articles and television programs (BBC 2001, NHK 2000), it has also been reported that there there has been effort by ex-patriot Indians living in the United States of America to fund an Indus Valley Museum in Baroda at a cost of some fifteen million dollars (Gokhal 2007).

Why is Predictive Modelling Useful in Studying the Harappans?

This is mainly due to the lack of data; as will be seen later in this research, granularity of ground resolution from satellite imagery and other sources available to this research is very low. Also only a few sites are currently being worked on and many have not been excavated at all, so even archaeological data is sparse. It is hoped that the gaps in this data can be somewhat filled by a predictive model algorithmically incorporating theories from other disciplines.

Thus, the predictive model will also benefit from the various theoretical models commonly used in other disciplines, for example, in terms of applying the use of common human geographical models. Social and political theory may also play a role in determining locational characteristics. It should be noted here, that it may not only be that a statistical correlation of some type exists with these and other models that is the determining characteristic, rather it may be that there is a negative correlation.

Thus, it can be seen that there are two major problems facing the research. The first is the lack of good quality visual data of sufficient scale. The second is the high volume of data to be processed from the various databases used in this research. Gowlett remarks on this type of problem in an article from the late nineteen nineties on the need for a "high definition archaeology"; a term which is used to encapsulate the idea of the process by which vast data sets are filtered in order to produce archaeologically meaningful results, that is, shifting the emphasis towards analysis rather than simply collection (Gowlett 1997: 152 to 153).

Computer Technology in Archaeology

There is a high degree of use of computer technology, mainly in the form of software in this research. For example, the construction of the predictive model, both to accurately predict Harappan culture port sites in the Gujarat as well as to validate current data. There is also a tendency to experiment with the use of computer-based software tools in an effort to use time more efficiently over the course of this research. Thus, it seems appropriate to briefly examine the current state of technology use in archaeology.

Computer technology has had a vast impact on every aspect of society, the economy and the environment globally. To say that it has been important to archaeology in particular is somewhat of an understatement given the use of three dimensional reconstruction, Geographical Information Systems (GIS), image enhancement of satellite, aerial and ground radar imagery and its many other applications. It is fair to say that computer applications in archaeology today have far exceeded the expectations of anything previously thought possible at the dawn of archaeological computing (Cowgill 1967). A simple example of three dimensional modelling in archaeology can be seen from a model of the Great Bath at Mohenjo daro (Appendix A: bath3d.zip) based on an axiometric reconstruction (Weaver 1966: 16) that has been built using a simple three-dimensional modelling program called *AC3D* (Invis 2003). This model has been built at a time shortly prior to the research planning stage of this study, more as an exercise in animation and modelling applications in archaeology, rather than to demonstrate any great scientific accuracy.

Given the ongoing rapid advance in computer software, hardware and the general availability of satellite photography through free computer software such as Google Earth and NASA World Wind (Google Earth Comparison 2005), archaeologists are now in a better position to take advantage of these tools and data and apply them to archaeological problems.

The importance of computers and computer technology in general have been to archaeology are many and included in the following are a few of more recent examples.

The satellite imagery gathered for the current research, thanks largely to the internet as eventually envisioned by Tim Berners-Lee (BBC 2007, Segaller 1999: 210), has been downloaded from a number of freely available sources such as the NASA web site (Goddard Space Flight Center 2003). Over the course of the research, this has been achieved with far greater ease due to freely available computer programs such as Google Earth and NASA World Wind (Google Earth 2005, Google Earth Comparison 2005). Imagery collected from these sources can then be loaded into external GIS programs such as ArcView for further geospatial analysis. Google Earth should be particularly noted in archaeology circles for its assistance to an Italian user Luca Mori who, in September 2005, discovered a Roman villa while looking at his home town of Sorbolo, near Parma via Google Earth (Butler 2005). Even the dissemination of archaeological publications themselves have further become ensconced on the internet and are already well known to academia with online electronic journals such as the Scholarly Journal Archive (Jstor 2009) and Science Direct (Science Direct 2009) as well as web sites such as Internet Archaeology (Internet Archaeology 2009).

One should also note the efficacy of a general interdisciplinary approach to any problem prevalent in this interface between archaeological science and high technology. An example of this is the use of computed tomography (CT) or CAT scan which uses specialised x-ray equipment to obtain image data from different angles around the body and subsequent computer processing to create a cross-section of the body (RSNA 2005). In August 2005 researchers from Berkeley, in conjunction with the Silicon Graphics computer, used a CT scanner to image the gold-plated coffin of an ancient Egyptian girl; the images were then processed to form a three-dimensional image of the coffin and its contents (Murphy 2005). The results were more accurate than any comparisons that could have been obtained by a more destructive investigation (Burke 2005).

The list of the ways in which technology has affected archaeology are, in fact, endless. Given the exponentially increasing power of computer processors known as Moore's Law (Kurzweil 1999: 104), it is likely that there will be an ever increasing use of computers as an aid to research. This multi-disciplinary approach applies particularly to landscape archaeology and has been remarked upon before by other noted archaeologists (Aston 2000: 49), because with this multi-pronged approach, consideration must be given to a

study of the natural landscapes (Grzymski 2004: 13), economic landscapes (Grzymski 2004: 14), political landscapes (Grzymski 2004: 16) and cultural landscape (Grzymski 2004: 18) through time. More recently, other researchers have commented on the need for a multi-disciplinary approach in science and in cultural and heritage based sciences, particularly in relation to computer based solutions (Lampe et al 2008: 20), because analysis of complex problems cannot be solved within one research domain (Lampe et al 2008: 19).

Although ready-made computer software such as Computer Aided Design (CAD) applications like AutoCAD (Autodesk 2000) have long been important to archaeology to create accurate site plans, or to show the distribution of artefacts at a site (Forte and Siliotti 1997: 196).

Other examples of modelling techniques used in archaeology can be seen in, for example, operational research previously used in engineering (Bleed 1991: 19) to test for factors that are sometimes unobservable directly by the use of event trees (Bleed 1991: 21).

The effect of computers on archaeological science has also become readily more apparent with the long establishment and ever growing importance of conferences such as Computer Applications in Archaeology (CAA). Indeed the focus of the CAA conference in 2006 is "digital exploration" which is also a strong indication of the trends explored in this research (Clark and Hagemeister 2006, Mathur 2008). As predicted earlier in the 1980s, it is rapidly becoming the case, where "archaeological computing" is becoming the domain of the "archaeologist rather than the computer specialist" (Richards and Ryan 1985: 212).

Rather than continuing with further examples, perhaps the best way to draw this discussion to a close is by concisely surmising the research in the following case study where the current state of modern archaeological practice and its relationship to technology can be observed.

Case Study: Archaeological Computing: Evaluating Archaeological Methods

The subject of this archaeological excavation was not only to discover new information regarding garden design, but was also an evaluation of archaeological methods and an opportunity to develop an appropriate methodology for the investigation of gardens (Frost et al 2004: 261). This has taken place within the settings of the kitchen garden and orchard at Royal Castle of Strimsholm in Sweden (Frost et al 2004: 261).

A site visit was deemed useful prior to map research and the study of other historical documents because it enabled a first impression to be compared with how this area has been documented in historical maps, plans, photographs, as well as, an overview of the history through via a literature search, thus while some details have been confirmed, others have not and new questions have been formulated (Frost et al 2004: 270).

Data collection included geophysical surveys, field mapping, crop mark analysis, rectified historical maps and aerial photography, archival documents and interviews with local residents; the results of which have been digitised, which allows information to be compiled on-site, enabling interpretation of findings and, thus, faster report production (Frost et al 2004: 261). In order for proper verification, archives have been consulted, thus saving time that could then be re-allocated to rectifying and interpreting historical maps and aerial photographs (Frost et al 2004: 270). All maps and photographs were digitised and having access to these via laptop computer during fieldwork was beneficial (Frost et al 2004: 270).

Water conduits and drainage constructions have been found as well as tree pits and paths and a medallion-shaped garden pond edged in limestone and the location of an older garden that pre-dates the present has been identified through crop mark analysis based on an aerial photograph combined with a rectified historical map (Frost et al 2004: 261). .

Geophysical surveys have added to the analysis, supplemented by details of the excavation; it has been found that the investigative methods have produced new

information and are demonstrated to be most effective when combined, thus, because no single method has led to a definitive interpretation of the findings (Frost et al 2004: 261). Geophysical survey indicated where paths and water conduits had been situated, but did not provide the entire picture unless combined with excavation, historical maps, the crop marks, Slingram and GPR (Frost et al 2004: 270), otherwise interpretation of the results could be extremely uncertain because of the level of material degradation (Frost et al 2004: 270).

The use of interviews, some of which have been verified through excavation, of persons connected with the former garden have been found to be a practical investigative method for collecting information concerning more recent history (Frost et al 2004: 270).

Excavation still, however, proved to the most effective tool, here revealing pond construction details and plant pits with preserved roots.

"Laptop archaeology", as described here, was thought to be a convenient way of collecting information in a single place and having all the information at hand on site and this assisted greatly in the interpretation of the findings and the excavation planning, as well as, enabling reports to be produced more quickly (Frost et al 2004: 270). Therefore, it was concluded that the laptop computer has been the most important tool during this research (Frost et al 2004: 261).

Attention is particularly drawn to both the utility of laptop, the need to combine different data collection strategies and the survival of excavation as a valuable archaeological skill, even given the current use of high technology.

Of course, the main factor in the use of any tool, computer technology included, is the need for planning as, although great benefits are possible, so can a great consumption of time and resources occur to little effect and it should be emphasised that any adoption of computer technology requires constant amendments to planning (Eiteljorg and Limp 2008: 263-264), a fact that has become abundantly clear during this research.

Summary

The subject of this research is to build and test the abilities of a site location predictive model in order to better understand the Harappan maritime trade network, including the probability and placement of port sites and thus, probable sea routes for trade and exchange activities.

It is thought that it should be possible to build a predictive model using data from varied sources such as archaeological records, remote sensing data, historical maps, topography, geology, environmental and ecological data.

As well as using traditional statistical methods, the model will also utilise various geographical, social and political theories, as well as a suite of various software tools and programming languages to create an effective and accurate model.

The Harappan Civilisation is fairly new to western archaeology and science. Thus, research about the Harappans is largely sparse making this course of research a fertile ground for testing novel approaches and sounding out new interpretations.

Therefore, this is an investigation into the use of, as well as, to extend and contribute to the field of digital exploration through the development of methodologies and modelling tools for archaeological reconnaissance.

Conclusion

Thus, it is established that the subject of this research is the identification of port site locational criteria for Harappan sites in the Gujarat through use of the latest available software.

The following chapter concerns the structural framework for this research effort.

Structural Framework of Research

Introduction

This chapter describes the structural framework this research.

The research is roughly divided between the descriptive, modelling and analytical stages. It should also be noted that throughout the research data will be collected and expanded upon, so that during the analysis stage additional time will be available to collate data, research findings and to organise results into a final thesis.

Software Development

Following on from this, the task of the development of a Harappan Ports Predictive Model (HPPPM) is further contained within a small sub-project using a generic and fairly commonly used format and roughly following a standard Information Technology (IT) plan for the development of a small software application. The methodology used can be described as a very non-formal hybridisation of structured, for example, Structured Systems Analysis and Design Method (SSADM) (Office of Government Commerce (OGC) 2001) and Rapid Application Development (RAD) (Hanna 1995) systems development methodologies, using a generic template as a guideline (Delaney and Brown 2002). Given the small size of this sub-project and the limited time available, the development life-cycle features constant and iterative prototyping. Many of the usual deliverables, in terms of project documentation, have been omitted in the interest of brevity and taking into consideration that this is social science research rather than pure computer science.

Research Life-Cycle

This consists of collating the various normalised data into a simplified data dictionary (see Table 5.1 Final Selection of Attributes). As well as standard software boilerplate headers in each script file, flow diagrams and standard software project documentation are also produced in order to properly document the entire development process. The database component will be implemented using a Relational Database Management System (RDMS). The traditional issue of speed will not be an issue as this is not a large dataset by modern standards (however see 7.4).

Design, Development and Testing

Bearing in mind the availability and quality of data, various algorithms are designed and implemented to perform various mathematical and statistical functions with a view to present a predictive model of the ideal Harappan port city. Each part of the software will be tested thoroughly in terms of robustness, accessibility and accuracy by manually completing each task before converting this manual procedure into a mostly autonomous computer program and then comparing the results of the two. This briefly describes the critical path of the research.

Summary

The research is split divided stages providing allocation of resources for planning, data acquisition, constructing the predictive model and analysing and interpreting the results.

The development of the predictive model will follow a generic format for the rapid production of a small software application and will include design, development, testing and the production of software documentation.

Conclusion

With the proposal explained and the structure examined, a beginning is made by first turning attention to predictive models in the following background study.

1 Predictive Models

1.1 Introduction

It is hoped that the predictive model designed in this research will assist in describing and explaining the mechanisms of the Harappan maritime trade network in the Gujarat area of North-West India. Therefore, part of the research consists of investigating the validity that existing sites, referred to in previous studies by other researchers as "port-cities" (Thakker et al 2000, Gaur and Vora 1999, Rao 1979) have indeed been used as beaching, docking or port areas as well as defining the distinctive criteria of possible new sites.

Due to the extreme limitation of the availability of high resolution imagery from satellite remote sensing and aerial photography, there is a limit as to the usefulness of remote sensing data in locating these new sites. Because of this, it is hoped that predictive modelling will prove invaluable as a tool for archaeological reconnaissance where satellite and aerial imagery is sparse.

First, a summation of the archaeological predictive modelling is offered in terms of definitions, case studies and the advantages and disadvantages inherent in the modelling process.

1.2 Definition of Archaeological Predictive Models

Before discussing the building of the predictive model for this particular study, perhaps a brief definition of just what is meant by the term "predictive model" in terms of this research and also what is hoped to be accomplished by building one.

Simply speaking, a predictive model is a comparison tool. The logic behind predictive models is described by Renfrew and Bahn who state that the "underlying premise for all predictive models is that particular kinds of archaeological sites tend to occur in the same kinds of place." (Renfrew and Bahn 2004: 93). Or somewhat more verbosely as "a

simplified set of testable hypotheses, based either on behavioural assumptions or on empirical correlations, which at a minimum attempt to predict loci of past human activities resulting in the deposition of artefacts or alteration of the landscape" (Kohler 1988:33).

The importance of predictive models in archaeology is that they are, or should also be analytical rather than, merely descriptive. In other words, rather than just locating a site, it should also help to develop an understanding of the relationship between human communities within their encompassing landscape.

However even using models to simply identify patterns utilising simple landscape attributes is a useful beginning to further historical research and by exploring the thought processes behind human activity using GIS methodologies a more holistic research approach is achievable (Fry et al 2004: 105).

1.3 Types of Archaeological Predictive Models

Following on from the above discussion, the following definitions, with a few exceptions are a summation of the study of Moon (Moon 1993) regarding the types of predictive model in use. This is a useful step both as a prior stage to examining some selected case studies and before describing the predictive model constructed for this research. Thus, archaeological models tend to be of either the following types or a combination thereof and it should also be noted that while the model designed later in this research shares characteristics of most of the following model types, it is closest to the older "Pattern Recognition" type (see 1.3.4 Pattern Recognition).

1.3.1 Intuitive

These models are those which are based on the experience, intuition or familiarity that a particular archaeologist may have with a specific landscape that they have grown accustomed to exploring and although it is difficult to quantify this kind of model due to its

highly subjective nature, however, subjectivity based on sound experience can prove invaluable (Moon 1993: 6).

1.3.2 Associational

These type of models are simple in that they generally use environmental data related to site location, that is, they associate or relate particular attributes to sites, thus they may give archaeologists an idea of where the site might be and also may be used as a basis for further research or funding and are easier to design than intuitive models because quantifiable data is used (Moon 1993: 7) rather than subjective opinion.

1.3.3 Areal

Areal models tend to predict certain characteristics such as density per unit of land; thus, are very simple, but often do not produce anything other than very general and relative statements about where sites may be found (Moon 1993: 7), such as "more sites will be found in this area than that one" (Altschul 1988:68).

1.3.4 Pattern Recognition

These are a class of predictive model popular in CRM is an areal-based pattern-recognition model which usually uses sample data to perform an algorithm which can be used to predict some aspect of site location (Moon 1993: 7).

However, the modern usage of the term "pattern recognition" now generally applies to applications using some kind of computer vision technique within the code of a program; where models contain algorithms that mimic vision in order to compare graphical elements (Daintith and Wright 2008). In some ways they are better than human vision in that the algorithm can be programmed to either ignore or include certain specific visual elements; something that is difficult to do with a human being. This kind of algorithm is now easier

to design with the advent of agent based programming languages, fairly easy to use graphical manipulation tools or graphics programming libraries in some programming languages.

1.3.5 Inductive

Also known as correlative (Moon 1993: 8) or empirical models, these work by finding correlations between site locations and the proximity of environmental variables (Ebert 2000:129). For example, if, in an inductive model, it is determined that a site always has a source of potable water one mile away and, when run, the model predicts another location with a potable water source also one mile away, it will determine that this is very probably the location of a new site. A strong criticism of this, however, is that the model will completely ignore the fact that this new site does indeed have a near-by water, however, that water is only reachable via a difficult climb up a steep hill. That is not to say that these models are not useful, only that one must use caution in deciding whether an attribute should or should not be considered in the model, though another criticism of these models is that they fail to take into account human behavioural systems. The HPPPM may include inductive aspects in that it uses data from known sites in the same area in order to find the same type of sites in a similar landscape (Gibson: 2005:209).

1.3.6 Deductive

Also called explanatory models, these are almost the opposite to inductive models in that instead of proceeding from data to theory, as is the case for inductive models, they start with a theory first. Given that they start with a theory these models are much more difficult and time-consuming to produce, but are, however, much better than inductive models because they tend to explain why something occurs in the landscape and then find these occurrences (Moon 1993: 8). Obviously this leads to far more accurate results than simply showing a correlation and then trying to fit a theory around this.

One observation that has been made is that there seems to be no strict delineation between the types, thus the simple fact is that all these techniques should not, and probably are not, used in isolation of each other, that is, they all have something to offer the archaeologist. As with most methodological approaches, if used in a logical combination, they can add up to more than the sum of their component parts.

After this brief look of the classes of predictive model that exist, attention is now turned from theory, to real world examples, starting with some short examples and then continuing at a more in-depth level with some detailed case studies.

1.4 Case Studies, Archaeological Predictive Models: Various

<u>Regge Valley, Netherlands: Site Location (Brandt et al 1992: 268)</u>

The importance of predictive modelling is also becoming more apparent in Europe as can be seen from a multiple period site location exercise in the Regge Valley Project, in the Netherlands (Brandt et al 1992: 268). Here, due to a lack of time, funding, detailed palaeoenvironmental reconstructions, random sampling and because extensive sub-surface exploration of buried sites are not possible in the study area; models have been designed based on known surface sites and on the relationships with mostly present environmental conditions (Brandt et al 1992: 270). The assumptions behind this work are that human behaviour conforms to a pattern and these patterns extend to choosing which areas are deemed desirable for settlement and, therefore, the selection of these areas should demonstrate non-random traits (Brandt et al 1992: 269). It is also believed by the researchers that most predictive modelling uses environmental data, such as soils, geology, hydrology and topography in preference to those of a social nature, for example, road locations, ritualistic locations and markets because this socially orientated type of cultural data is far more difficult to obtain and, for this reason, their project uses solely environmental attributes (Brandt et al 1992: 269). Here, a "weighted map-layer approach to modelling in a Geographic Information Systems" is adopted where each category is assigned a weight pertaining to whether the conditions are "favourable" or "poor" for archaeological site location, for example, where certain soil types might be favourable for

a farming settlement while others are not (Brandt et al 1992: 271). The final selection of attributes includes soil textures, geomorphology, surface area, ecological boundaries, for example, highland and lowland ecologies and distance to water or ecological boundaries because both are likely to be water sources (Brandt et al 1992: 273). According to the researchers, within four years of use the model has assisted in the discovery of fifty-two new sites with twenty-four percent of these sites having been found in areas the model predicted as being strong candidate areas for searches (Brandt et al 1992: 278). This has been considered a favourable success rate by the researchers and suggests that the model is able to locate areas based on specific critical factors, the model can utilise even biased data from existing records and these rather approximate methods used in the model can still produce satisfactory, robust and testable results (Brandt et al 1992: 278). The researchers go on to state that predictive modelling can only indicate trends in surface site distribution and these trends cannot be further narrowed down to the specific nature of sub-surface details concerning these sites (Brandt et al 1992: 278). They finally conclude with a strong warning to the affect of not using archaeological models based on solely surface data for planning while neglecting to investigate sub-surface features that are of equal importance and also equally deserving of any conservation efforts (Brandt et al 1992: 278). Similar types of site location modelling examples in Europe can be seen in a recent review of archaeological predictive modelling from the Netherlands (van Leusen and Kamermans 2005).

United States of America, Illinois, Shawnee National Forest: Site Location

Colin Renfrew and Paul Bahn, in the standard text for archaeologists- *Archaeology: Theories Methods and Practice* (Renfrew and Bahn 2004), in the section discussing site location, GIS and predictive modelling (Renfrew and Bahn 2004: 89), mention the work of Robert E. Warren whose research is described in *A predictive model of archaeological site location in the western Shawnee National Forest* (Warren 1987). This work is mentioned with a view to emphasise that many major developments and also the usage of site location predictive models have been pioneered in the United States of America (Renfrew and Bahn 2004: 89). The project discussed concerns a model developed by the Illinois State Museum for the area within the Shawnee National Forest in southern Illinois, the purpose of which is to predict the probability of discovering a prehistoric site within a range of

ninety-one square kilometres (Renfrew and Bahn 2004: 89). The model accomplishes this by utilising environmental data, such as elevation, slope, aspect, distance to water and depth to the water table that has been gathered from surveys of sixty-eight sites that have been previously discovered in an area of twelve square kilometres (Renfrew and Bahn 2004: 89). The environmental characteristics of these known sites are used by comparing the information about these sites to the environmental features of locations that are known to not currently contain discovered sites using a technique called logistical regression; the result of which is algorithmic formula that may then be used to estimate the possibility that a location for which environmental data exists may contain a prehistoric site (Renfrew and Bahn 2004: 89).

This technique of logistical regression, central to this model, concerns the determination of relationships by using mathematical calculations to create graph plots of values, then, using these plots, there are three ways to determine whether one entity is related to another. A graph is first created for a group of values and then a line of best fit is determined in the usual way (Bidger 2007). There is, however, more than one way to determine a line of best fit (Bidger 2007). These lines can either be linear, that is, straight, parabolic, that is, curved or, finally, logistical, that is to say, "S" shaped and thus, in this way logistical fittings differ slightly from conventional basic mathematics (Bidger 2007). The benefit of these "S" shaped curves are that they allow probability to be taken into account (Bidger 2007). It should be stated that logistical regression techniques can involve some fairly complex mathematical procedures and this is a highly concise explanation, hopefully phrased in simple, non-mathematical terms. However, there are problems that can occur with this technique when poorly applied (Woodman and Woodward. 2002). Following on from this, a test of the effectiveness of logistical regression can be seen from the work of Maschner and Stein (Maschner and Stein 1995). Their research concerning the location of prehistoric sites, uses logistical regression in the belief that the technique is "both robust and open to field evaluation and statistical replication" (Maschner and Stein 1995: 61). They conclude that the technique is indeed a capable one for use as a methodology for the investigation of particular landscape requirements (Maschner and Stein 1995: 72).

For further reading, attention might also be drawn to logistical regression techniques that have been used in an ecological study of vegetation patterns, where vegetation type have

been recorded as pixels in a grid at different times in order to examine changes in semi-natural vegetation in north-east Scotland (Augustin et al 2001).

Canada, Ontario, Thunder Bay: Site Location

There is a CRM study in the Canadian province of Ontario, where predictive modelling has been developed for the purposes of forest management by researchers at Lakehead University due to concern that the Ontario Ministry of Natural Resources (OMNR) has with the protection of the cultural resources of the province (Dalla Bona 1994). The team at Lakehead University in Thunder Bay, Ontario has been tasked with the development of a "computerised decision-making model" to assist forest management planners to identify areas that are most likely to contain archaeological sites (Dalla Bona 1994). Again, the use of archaeological predictive models as a decision support tool is seen. It is thought by the researchers that archaeological predictive modelling offers new opportunities to CRM in a geographic location where other standard techniques are too difficult to apply because of size of the area involved and the lack of access due to poor communications (Dalla Bona 1994). There are also the problems of visibility due to dense vegetation, thus the researchers hope that the study will enable the production, test and use of a prototype predictive model to assist in forest harvest planning (Dalla Bona 1994). Following this research, several recommendations have been proposed, these include factors such as the need for the prototype model to be more thoroughly tested in areas similar to those that it has been developed for, the model is designed for a specific region, therefore, the value of its use outside this area is unknown, thus before it can be used elsewhere, it should undergo a period of further testing, further attributes also need to be identified and tested so as to improve the performance of the model through a process of tuning and more data is available for the model to use and this has not been fully realised as yet (Dalla Bona 1994). Therefore, they believe that an effort needs to be made to evaluate the range of data available within the Ministry of Natural Resources and that the transformation of the model from a prototype to a production system must occur by evaluating the final needs of the heritage management function including staff education and training for the final users of the model (Dalla Bona 1994). The model is designed to assist in investigating mainly prehistoric archaeology; other cultural heritage issues as they pertain to lumber management have not been addressed and these aspects require further investigation (Dalla

Bona 1994). There are also other applications that this model can assist with, including the planning and development of pipeline corridors, transmission lines, hydroelectric reservoirs, urban development and cottage development (Dalla Bona 1994). It should finally be noted that the researchers believe that archaeological surveys are a vital part of government policy in particular, both due to land-claims of various aboriginal bands as well as the desire, one hopes, to preserve the archaeological heritage of the land.

These surveys are also not limited to publicly owned land, for instance, in areas where commercial hydrocarbon extraction is prevalent, such as parts of northern British Columbia, each time a pipe-line is either re-routed or an addition constructed, there is an obligation by the companies that own the pipe-line to commission an archaeological survey of the area prior to further disturbance.

<u>United States of America, Minnesota: Site Location</u>

Another example of a model created to aid in cultural resource management is the Minnesota Archaeological Predictive Model (Mn/Model) from North America; the project, from 1995, originates with the Minnesota Department of Transportation as part of a major environmental management efficiency programme (Hobbs et al 2005). The model is a state-wide GIS-based predictive model for pre-1837 archaeological sites and assists in meeting the requirements of the National Historic Preservation Act (Hobbs et al 2005). The model consists of high-resolution digital maps that help show planners and cultural resource managers the possible presence archaeological resources; the maps are developed using both GIS and statistical modelling in order to create more efficient, cost-effective and reproducible models (Hobbs et al 2005). The model is dynamic in that it assigns high, medium and low site probabilities based on correlations between existing site locations and environmental variables; the model is improved over time as new data becomes available (Hobbs et al 2005). The model also incorporates temporal transformation features of the Holocene landscape; this distinct characteristic, at the time of the project, is thought by the researchers to have been a unique feature for a model of this size (Hobbs et al 2005). The results of model have been incorporated, at an early stage, into project planning, thus assisting transportation planners of the possibility of new sites and allowing avoidance strategies or surveys to occur (Hobbs et al 2005). The model also assists in budget and

schedule estimates for individual projects as well as long term tasks and this is also model developed to cover a large geographical range and, in fact, covers the entire extent of the state of Minnesota (Hobbs et al 2005); this is a large area of the United States of America of approximately two hundred and twenty thousand square kilometres (Minnesota 2007) in area, bordering eastern Canada to the north. The model has been created with a view to providing archaeological site location probabilities and survey bias information, as well as data concerning survey implementation and the makers of the predictive model have stated that, in the model, approximately twenty percent of the area covered contains the potential for high and medium site distribution, and that most of the remaining area of around eighty percent already contain known sites (Hobbs et al 2005). The cultural resource management aspects of this predictive model can be seen from the inclusion of the survey bias function which is a useful tool in assisting cultural resource managers to ascertain whether areas have been sufficiently surveyed in the past and whether further surveys are necessary, additionally, the inclusion of the survey implementation function allows informed judgements to be made about whether various land development projects are likely to have an impact on state archaeological resources (Hobbs et al 2005). The project team believes that they have developed an easy-to-use tool that can be used in several ways, that is, it can be used for assessment of environmental data and models as well as developing geomorphological maps for understanding potential for sub-surface sites (Hobbs et al 2005). They also believe that the GIS data analysis and modelling methodologies and standards that have arisen from this research can be extended to other related applications and they conclude the paper by stating that the predictive model they have developed is a set of GIS based tools that can assist in the avoidance of situations that may have impacts on archaeological sites throughout the state of Minnesota (Hobbs et al 2005).

<u>United States of America, Delaware: Site Location</u>

Another site location predictive model concerns the coastal plains area of the state of Delaware in the United States of America where a team have developed methods of using LANDSAT satellite data in archaeological predictive models for site location (Custer et al 1986: 572). The original impetus for this four year joint-research project by the University of Delaware Center for Archaeological Research and the University of Delaware Center for

Remote Sensing has been to research methods for the direct application of LANDSAT remote sensing data in order to develop archaeological predictive models (Custer et al 1986: 573). Again the purpose of this model is to provide information relating to cultural resource management problems as well as data about prehistoric land use patterns, thus the model uses mainly environmental factors in determining the probable likelihood of site presence in any particular area (Custer et al 1986). This is accomplished by a statistical method known as logistical regression (Custer et al 1986: 574) described earlier (see United States of America, Illinois, Shawnee National Forest: Site Location, Warren 1987, Bidger 2007) and uses LANDSAT data to locate archaeological sites (Custer et al 1986: 574-575). However, because resolution of the LANDSAT data is low, it is generally unsuitable for the remote sensing of archaeological sites, hence, the researchers have used an alternative approach where, rather than searching particular attributes associated with archaeological site locations, a combination of attributes including distance to surface water, soil drainage and the topography can be correlated with known locations of sites; the researchers call this a "synoptic" approach and believe that this methodology can increase the usefulness of LANDSAT data in archaeological predictive models (Custer et al 1986: 573). According to the researchers, the reason that this is significant is that LANDSAT environment data is widely available throughout the world and processing this data is possible using inexpensive personal computers (Custer et al 1986: 583). The researchers believe that this type of modelling can have important applications in cultural resource management and has already been used in a planning study for a major road development with initial testing showing that the model can accurately predict site locations and it is thought that the model can also indicate areas that require special attention during surveys (Custer et al 1986: 575). They do, however, state an opinion common with many modellers, that the model should not be regarded as a replacement for field work and that the model also requires further testing and tuning and that predictive models can be used to focus the development of sampling plans, though any further utility would require an improved model (Custer et al 1986 :575). They conclude by stating that the model, as well as being useful to cultural resource management, can also assist with research into prehistoric land-use patterns (Custer et al 1986: 575).

United States of America, Pacific North-West: Social Complexity

This PhD research project from the University in Southampton in the United Kingdom concerns the archaeology of fjord land archipelagos in the Pacific North-West Coast of North America (Mackie 1998: ii). The motivation for designing this model is in order to examine hunter-gatherer communities from a smaller, more human perspective. He states that previous investigations into hunter- gatherers have been more concerned with studying the origins of social complexity, however, issues of social complexity are complicated and the straight-forward classification of "hunter-gatherer" is problematic (Mackie 1998: i). Therefore, this predictive model, to some extent, also attempts to take into account geography and social theory in order to ameliorate these deficiencies in categorisation. Mackie believes that the advantage of this approach is a more "subtle, humanistic conception of time and space…weighed against more formal models which define real spatial patterns" (Mackie 1998: 6). In terms of its relevance to research in predictive modelling techniques, Mackie believes that incorporating the shape of the environment in what he calls a "non-site landscape approach" has possibilities for predictive modelling because interesting patterns have arisen in the data, for example, midden areas that are neither villages nor large sites, but a clustering of many small sites (Mackie 1998: 175). He also believes that, in the future, predictive modelling will include larger land-form data as well as smaller micro-environmental features and a regard for the built environment (Mackie 1998: 175). Mackie goes on to state that he regards his research as a useful first stage and that there is a requirement to use this methodology in other fjord-land environments, for example, the southern Queen Charlotte Islands of British Columbia in Canada, to determine whether similar patterns arise there also (Mackie 1998: 175). Finally, he once again champions the use of combining aspects of social theory with archaeology, or as he says, "This middle ground in archaeology…the alliance of social theory to quantitative geography" enables the "production of demonstrable, testable results" (Mackie 1998: 177).

United States of America, Arizona, Tucson Basin: Temporal Aspects

This PhD research concerns the prediction of locations likely to contain archaeological material where there is known to be a statistical relationship between known

archaeological sites and their local environment from a perspective of a standard criticism of archaeological predictive modelling, that is, the assumption that sites are mostly of the same time period and the environment remains in a state of stasis (White 2002: ii). Thus, by taking into account factors not necessarily initially thought of, the project attempts to model site locations in the Tucson Basin area of Arizona; these factors include the temporal dimension of change over time (White 2002: iii). To accomplish these aims, GIS is used combining satellite imagery data with GIS specific data, such as digital elevation models (White 2002: 94). He concludes with several points of consideration. GIS use in archaeology is increasing, as both an effective management and an analytical tool. Archaeologists have used GIS to answer many questions, these include studies concerned with site catchments, the significance that view, or line-of-sight has to site location, the costs in terms of energy expenditure for movement, trading networks, migration patterns and borders locations. The research has examined the process modelling and the problems of a non-temporal techniques while proposing an alternative strategy to alleviate these problems while also assist identifying change trends. He believes that it must be remembered that landscapes, cultures climates and ecologies change during the time span of human occupation. The final point made is that, although the technique is effective, it requires substantially detailed data sources and one can expect an "exceptional" amount of time, storage and complexity to added to the task (White 2002: 144-145).

United Kingdom: Bayesian Techniques

There is also a study on the use of Bayesian techniques in predictive modelling from the University of Southampton in an attempt to increase the accuracy of their models (Buck and Sahu 2000: 423).

Briefly Bayesian techniques are a way of determining probabilities. Unlike other probabilistic methods, however, it uses reference data to make comparisons, but then also adds candidate data to the reference data if it is deemed to match closely enough. In this way, if more data fed is fed into a Bayesian model it performs well, also the model constantly evolves becoming more accurate at each turn. In other words it is a learning algorithm. "The essence of the Bayesian approach is to provide a mathematical rule explaining how you should change your existing beliefs in the light of new evidence"

(Murphy 2000). Bayesian methods are widely used outside archaeology for many systems that are required to learn. The most common use of Bayesian methods today use today is in anti-spam systems for e-mail filtering. It should be noted that Bayesian techniques are not entirely risk-free systems. Using the same example of e-mail filtering, without occasional user intervention in terms of manually correcting e-mail wrongly marked as spam, the filtering technique can begin to remove e-mail that is not, in fact, spam. By projecting these same hazards into the realm of archaeology, it can be seen that Bayesian systems need to be "tuned" in order to function satisfactorily. Although it later fell into disuse partly due to objections to its subjectivity, it experienced a resurgence in the 1980s due to a combination of the availability of increased computational power and the need to describe complex systems in science (Brooks 2003: 26951-2682).

The research of Buck and Sahu relate to novel techniques employed seriation studies in order to develop relative chronology models; so called "seriation" techniques involve attempting to reconstruct relative chronologies based on the density artefact types found in excavated features even when stratigraphy is absent; the data used in such studies are the amount of a specific artefact type within a particular archaeological feature (Buck and Sahu 2000: 423, 424). Such data is compiled into what is variously known as a cross-classification table or abundance matrix or a contingency table (Buck and Sahu 2000: 423). Once this table is compiled various statistical techniques may be applied to the data in order to try and reconstruct a relative chronology (Buck and Sahu 2000: 423). Buck and Sahu have developed model-based approaches that they believe might be used to aid in building these relative chronologies (Buck and Sahu 2000: 423). The predictive modelling aspect can be seen in their use of Bayesian modelling techniques that are used to determine the plausibility of the models (Buck and Sahu 2000: 423).

Thus, it can be seen that Bayesian statistics should be applied where problems occur that simpler statistical tools, such as t-tests, cannot be applied to complex problems (Brooks 2003: 2695) and complicated interactions, as can be seen here, are not uncommon in archaeology. Further and more mathematically precise definition of the methodology can be found in the work of Smith (Smith 1991).

United States of America, Alaska: Impact Assessments

There are also another two site location models for cultural resource management based in the United States of America that will be mentioned here. Both impact assessment studies undertaken by private companies for specific areas of Alaska (HDR 2003, HDR 2005). The first project is a proposed study in the Cooper Lake area and is tasked with determining the impact of an existing hydroelectric installation (HDR 2003). The other completed project is in the Stetson Creek area and is concerned the impact of the diversion of this creek for the same hydroelectric installation mentioned above (HDR 2005). These projects go some way to proving that predictive models are no longer purely the domain of academia and are of use and value in the private commercial arena as useful techniques (HDR 2003, HDR 2005).

It is hoped that the above summary of various predictive models, most pertaining to archaeology, heritage management and conservation, gives a concise insight into the current state, issues and techniques of predictive modelling, particularly with respect for site location models from around the world.

It can be noted in passing that many of the projects described above share some of the concerns and issues with the Harappan model being designed in this research. A useful example can be seen from the Ontario forestry project described earlier. For example, the researchers feel that there is a need to move and somewhat make changes to the model so that it may have real-word application. This is also felt to be the case here because, in order to create a future generic predictive model, multi-environment, multi-culture model it will be necessary to subtly transform the Harappan model.

Attention is now focused on a particular example that comes quite close to what is being attempted in this research; *Site location model for shipyards in Maryland, United States of America* (Ford 2006). This shall be examined in the more detailed case study that follows.

1.5 Case Study, Archaeological Predictive Model: Shipyard Locations in Maryland

This case study focuses on the research into ship-building sites in the Chesapeake area of Maryland in the United States of America from the 17th century onwards (Ford 2006: 125). Due to the lack of recorded data concerning the location of these sites, historical documents in the form of land transactions have been coupled to a GIS (Ford 2006: 125). A predictive model is then constructed based on six environmental factors- proximity to cities, shelter, slope, soils suitable for construction, soils suitable for oak growth (ship-building material), absence of soils for greater agricultural economic value; mainly tobacco growth (Ford 2006: 125).

Similar to the research being conducted here, the project has had to contend with many gaps in the data-set. Although 181 sites had been identified from previous research using historical records, it is thought that only 95 of these sites of possible shipyards are viable for further analysis due to lack of data (Ford 2006: 130). Of these, only two sites have been identified from the archaeology (Ford 2006: 131). In order to alleviate this lack of data, the six environmental factors mentioned below are used (Ford 2006: 131). These factors are then statistically weighted and added to a map-layer in the GIS which, in turn, displays high, moderate, and low probabilities for shipyard locations (Ford 2006: 125). The weightings are as follows (Ford 2006: 132)-

-Areas within 8 km of a historic city are valued at 5
-Areas between 8 km and 16 km are valued at 2
-Soils beneficial to oak are valued at 5
-Soils beneficial to the growth of tobacco are valued at -2
-Slopes between 6 and 8 degrees are valued at 3
-Regions with slopes between 4 and 6 degrees and between 8 and 11 degrees are valued at 1

Results with scores from 0 to 3 are considered low-probability, 4 to7 moderate-probability, and 8 and above high-probability (Ford 2006: 132).

The validity of the model is later checked in the field by attempting to identify any potential shipyard-sites by sight (Ford 2006: 132).

Ford concludes that a combination of four factors are necessary to identify shipyards using the method described (Ford 2006: 134):

-Approximate descriptions drawn from the historic record
-Application of the predictive model
-On-site evaluation of the predicted area using visual experience, local informants
- Good site preservation.

He also believes that the historical record and the predictive model will place a researcher in approximately the right location, but it requires an experienced researcher to conclusively identify the site (Ford 2006: 134).

Further, that the only reliable way to determine presence or absence of shipyard will be through archaeological excavation necessary in terrestrial and submerged contexts using the associated tools such as side-scan sonar, sub-bottom profiler and magnetometer, because infilling and erosion may have substantially changed the shoreline in the vicinity of a potential site (Ford 2006: 134).

He also states that it may be possible to rank the search area hierarchically, based on perceived indicators of features (Ford 2006: 136).

This new data can then be added to the predictive model or taken into account during initial surveys to identify more accurately probable shipyard locations and help narrow the search areas (Ford 2006: 136).

Additional possible predictive factors can be modelled and tested using GIS and should these factors prove to be valuable predictors, they can be added to the model and the high-sensitivity areas easily regenerated to produce a more accurate predictive model (Ford 2006: 136).

The model is effective for the eastern United States during much of the Colonial and early post-Colonial periods, however, there may be other factors necessary for consideration if a similar model were to be built to identify shipyard sites in a different region (Ford 2007: 136).

The research concludes by stating that the "list of factors is only limited by the archaeologist's imagination" (Ford 2006: 136).

Despite the closing statement, the actual choice of factors in the above research is small. Another point to note is that the model is not considered robust enough to be used without additional fieldwork. As is seen throughout the research, predictive models are complicated to build, difficult to populate with the necessary data to make them effective and do not seem to inspire confidence in their use on anything other than a broad scale. This is not to say that they have no use, simply that they are not a tool that can yet be used without resort to other more traditional archaeological techniques.

During, the building of this Harappan predictive model for site location similar problems of scale have been encountered, as well as problems in sourcing data and narrowing down the usefulness of attributes. Choice, has become somewhat of an enemy in terms of the dilemma faced when selecting attributes from a vast pool of possibilities.

1.6 Case Study, Archaeological Predictive Model: Archaoprognose Brandenburg

The case studies described before are rather brief, mainly due to the information contained in the various publications they have been obtained from. Also much of the information explains the aims and objectives of these models, rather than a more tangible flavour or blueprint of how these models may be built. It is thus prudent to conclude by examining a case study that includes substantial information about the procedures involved in the actual construction of a site location predictive model in archaeology in order to further illustrate the commonality of development stages in these types of model to the reader. Although, the work described in this case study has not been used as a guideline for this research, the

fact that many of these stages are shared demonstrates that the model-building process is not overly complex and is reproducible.

Also, whereas the case study of the PROSPECTOR (see 1.7.4), examined in this research, resembles the intent of the model created for this research, the case study that follows resembles the actual form of the HPPPM in terms of data acquisition, basic methodological parallels in terms of database usage and comparison techniques.

Thus, the following case study is taken from the research project *Archaoprognose Brandenburg* (Ducke and Munch 2005: 93-107) from north-eastern Germany. Although, at the time of article, the project was not yet wholly complete, it is useful in that it focuses on the methods used in creating a predictive model rather than a simple descriptive narrative. The work is subdivided into data acquisition, data processing, model building visualisation and application (Ducke and Munch 2005: 93). The application or ultimate goal, in this case, is to produce results necessary in order to carry out cultural resource risk assessment, where risk is defined as the possibility that any particular area may contain archaeological sites (Ducke and Munch 2005: 94).

The geographic range extends throughout the federal state of Brandenburg which covers an area of thirty thousand square kilometres and within this area, there are recorded approximately twenty-five thousand archaeological finds, the majority of which are by amateurs (Ducke and Munch 2005: 94). Although finds are distributed around the state, they also form clusters in the north-east, south-east and in the west (Ducke and Munch 2005: 94). Most of the finds are dated from the Neolithic period, approximately 5200 BC to around 700 AD to 1200 AD, with Palaeolithic and Mesolithic sites forming the minority and Medieval settlements continue into the modern period as present-day towns and cities (Ducke and Munch 2005: 94).

The model, although originally designed as a tool for academic research and heritage management, has, due to the costly nature of land development, the opportunity to development into a valuable tool for ascertaining archaeological site potential and, thus, reducing costs in terms of obligatory state sanctioned site assessments by land developers (Ducke and Munch 2005: 94-95). These opportunities have been realised following a

conference in 2001- *The Archaeology of Landscapes and Geographical Information Systems: Predictive Maps, Settlement Dynamics and Space and Territory in Prehistory* which has been important in drawing attention to the importance of including the following aspects as vital constituents of a predictive model- broad identification of site potential, information that includes economics, environment and settle behaviour, recognition of varying data quality issues and quantifiable estimations of accuracy (Ducke and Munch 2005: 95). Of these aspects ecological-environmental reconstruction and data quality have been deemed to be particularly necessary (Ducke and Munch 2005: 95). To ensure this quality, tests have been conducted with the data set, by splitting the data about find sites into two databases based on pre-1980 and post-1980 records in order to ensure that site prediction remained the same when using both sets of data (Ducke and Munch 2005: 95). 1980 is the chosen split date because it enables the two test data sets to be of roughly equal size and after testing, it has been found that the model has an accuracy in excess of eighty percent (Ducke and Munch 2005: 95).

Initially, the project uses seven sample areas of thirty to fifty square kilometres because they each represent different geological and archaeological environments of the region (Ducke and Munch 2005: 95). The data for each sample region consists of all available sources of information; this data is acquired, digitised and converted into GIS layers (Ducke and Munch 2005: 95). The data includes topography, aerial photography, historical maps and hydrology maps at varying scales of resolution (Ducke and Munch 2005: 95). For historical reasons, the Brandenburg region has been heavily surveyed and mapped since the eighteen century, however, since this data does not conform to modern standards it is difficult to incorporate it into a GIS system, though it does offer valuable insights about the pre-industrial landscape useful in reconstructions of the prehistoric environment (Ducke and Munch 2005: 95). The communist era after the Second world War and until 1990, held large political and economic changes and this is seen in the maps of the time, though due to differing cartographic standards and a bias towards military data, information useful in archaeology, such as land use and soil quality is absent, though these shortfalls have been filled from older, pre-Second World War Prussian soil type maps, additionally, a source of aerial photography has been the Luftwaffe of Axis Germany and later the Allied air forces which are publicly available (Ducke and Munch 2005: 96).

Much of the data previously described has had to be digitised from paper or film format using up approximately two-thirds of project time in order to create GIS layers; an elevation model has been created by scanning the contour lines of topographic maps as vector data and also manually entering elevation values and soil maps have also had to be manually digitised prior to their addition to the GIS (Ducke and Munch 2005: 97). Map layers of differing time periods have been combined to reconstruct a landscape vastly changed by later open-cast mining (Ducke and Munch 2005: 98).

Following on from this, the stage of the Brandenburg project concerns the creation of a database to hold data from the archives of the heritage management administration of the state; a process that involves time consuming archival work in order to verify site coordinates (Ducke and Munch 2005: 98). The researchers again emphasise the time-consuming aspect of this work and also that the quality of the data is extremely variable even across relatively small areas due to the records being based on different data sources; from amateur field surveys to professional fieldwork (Ducke and Munch 2005: 98). It is further stated that the highest quality data constitutes the smallest part of the database and it is for this reason, even at an early stage of the project, that it is thought that a more detailed investigation of data quality issues is required (Ducke and Munch 2005: 98). These further validation procedures include additional field surveys, though these verification exercises proved the original surveys accuracy, however, overall data quality has improved by the addition of extra information such as those available from aerial photography and core samples and this has led to a more precise search at particular locations (Ducke and Munch 2005: 98). Because all surveys have been carried out with a limited staff due to resource limitations, it is thought that a larger pool of surveyors such as a group of university students; a plan which did not come to fruition here, could be more successful in providing better and less biased information (Ducke and Munch 2005: 98).

The hydrology information has been assembled with great attention to detail because it is known that prehistoric settlements often value proximity to non-saline water sources, as well as because of the great biodiversity of such areas, it is also due to the role of these water bodies as a transportation network and this network spans much of the expanse of prehistoric European (Ducke and Munch 2005: 100). An attempt has been made to reconstruct these waterway networks by the interpretation of geological features that can

be seen in aerial photography and historic maps and it has been found that vertical aerial photographs have been particularly useful for this task (Ducke and Munch 2005: 100). The aforesaid historic maps are useful because of the substantial changes to the landscape during the post Second World War Soviet period for purposes of communal farms as well as the introduction of agriculture on an industrial scale (Ducke and Munch 2005: 100). The Brandenburg team believes, however, that the major waterway networks of the prehistoric era for this region have been accurately reconstructed using the sources mentioned (Ducke and Munch 2005: 100).

The quality of a predictive model is measured against data that is as representative of its sites as is possible, however, in practice, distribution of sites is influenced by numerous factors, one of which is land-use, which can affect the probability of site detection for buried sites and, in turn, affect subsequent management strategies; in this way, land-use and management issues can introduce bias to archaeological research (Ducke and Munch 2005: 101-102). Care must be taken, therefore, to investigate and evaluate these biases in conjunction with the predictive model- an example of this phenomenon can be seen in one of the test areas of the model; this is an open-cast mining area which has been continually observed and documented (Ducke and Munch 2005: 101-102). Thus, through this documentation, the area has provided much archaeological information of a high quality in terms of high resolution data covering space, time and a large number sites (Ducke and Munch 2005: 101-102). The continued recording of landscape changes due to the mining post-1990 means that distribution patterns formed by these sites can be considered representative and, thus, predictive models based on this data should be accurate (Ducke and Munch 2005: 101-102). In contrast another test area is not so well documented and only partially covered by student surveys with much lesser sites surveyed overall; it is known that the number of sites the area contains is artificially low because many have yet to be discovered and this has been proved through pollen analysis confirming that cereals have been cultivated in this area from the Neolithic onwards (Ducke and Munch 2005: 101-102). Other test areas also show uneven site distribution and this is accounted for by the surveys of amateur archaeologists whose research interests often differ due to personal preferences and, in fact, most of the test areas are of this type; examples of these personal preferences can be seen from one area where the amateur archaeologist prefers to walk a certain route that has proved productive in finding other Neolithic sites in the past and the

preferred means of transportation for travelling to these areas mean that the areas searched are within access of motorways (Ducke and Munch 2005: 101-102). In addition, higher land is avoided so as not to stray far from the motorway; these preferences lead to an obvious bias that has little to do with the real picture of site locations (Ducke and Munch 2005: 101-102).

In order to account for the variances of data collection strategies, studies have been carried out cross-referencing field walking activities with pollen sampling in order to determine whether some areas have not yielded as many find sites due to a lack of sampling, or because they indeed are unsettled areas (Ducke and Munch 2005: 102). To reduce the bias introduced by such unevenness of sampling, test areas have been selected that are of a certain landscape type and well documented (Ducke and Munch 2005: 102). A further data bias model has been produced in order to create an overall more accurate and useful tool for risk assessment (Ducke and Munch 2005: 102). For decision support purposes and to aid heritage management tasks, the potential for future site preservation is also thought to be of value (Ducke and Munch 2005: 102). The Brandenburg team expresses the view that site preservation is determined by geomorphology in terms of soil erosion processes and soil deposition (Ducke and Munch 2005: 102). Further, that the size and directions of these processes can be derived from the model itself, provided that data for topography and soils is available and that this data has remained at a relative constant since prehistory (Ducke and Munch 2005: 102).

The final stage of the model building process is what the researchers have called a "suitability" model, this is a formula for calculating the attractiveness of a location for settlement in prehistoric times (Ducke and Munch 2005: 103-104). Here the team has examined environmental attributes characteristic to specific locations, using statistical techniques in order to identify possible relationships between these attributes and site distribution which are thought to represent relationships between prehistoric and modern site distribution (Ducke and Munch 2005: 103-104). Next, knowledge about these relationships is used to quantify the "suitability" or attractiveness, mentioned earlier, of a specific location for the development of a settlement (Ducke and Munch 2005: 103-104). Numerous traditional statistical and mathematical techniques can be used to achieve these results, however, it is thought by the researchers the most useful techniques are those based

on probability (Ducke and Munch 2005: 103-104). In the Brandenburg region at present, without use of the predictive model, cultural resource management base their criteria for making decisions on the following factors- areas of up to two hundred metres from surface water and areas with a radius of one hundred metres around currently known to exist sites are thought to be likely areas in which further sites may be found (Ducke and Munch 2005: 103-104). Even using these criteria, heritage managers know that, in reality, the actual location of sites can range radically outside these assumed parameters and it is for this reason that a great deal of other data, such as archival material and aerial photography are used to additionally identify favourable search areas (Ducke and Munch 2005: 103-104). It is this type of labour-intensive and expensive planning work that the predictive model is endeavouring to ameliorate, however, with various mathematical techniques tested with the same data set, to what extent the model has achieved this is open to debate (Ducke and Munch 2005: 103-104). The problems can be seen from examples such as an extreme case where every site is deemed to be attractive with no differentiation in discrimination, thus rendering the model ineffectual (Ducke and Munch 2005: 103-104). However, even if this phenomenon is avoided by greater differentiation; by sub-dividing areas into those of high and low attractiveness for site location, a further problem occurs when there are too few sites to group leading to a situation where generalisations are important in order to find some commonalities within such a small group (Ducke and Munch 2005: 103-104). On balance, though, the Brandenburg researchers have found that most sites are found in areas of high attractiveness or "suitability", but these areas are large; using less complicated techniques and a smaller data set, however, also seems to have produced similar confirmatory results (Ducke and Munch 2005: 103-104).

In order to present complex information in a simple manner to aide to non-specialists working in cultural resource management tasks such as risk assessment, the final output of the modelling process is hoped to be in the form of both a digital and paper map with a single layer containing simple, easily accessible visual information (Ducke and Munch 2005: 105). Here the team considers the use of Bayesian techniques to combine information about suitability, conservation and uncertainty into graphically discrete values, such as colour, on the map (Ducke and Munch 2005: 105).

Many valuable insights into problems faced in creating predictive models have been gained by the Brandenburg team, these problems include the difficulty of how data such as informal knowledge and social variables may be incorporated into a GIS layer; these types of data include social or cultural processes, or combinations thereof (Ducke and Munch 2005: 105). In addition, the team believes that the source of some spatial patterns cannot easily be determined as to their origin in terms of non-environmental attributes of site location such as symbology that may possibly have been displayed in the architecture or the manner of cultural depositions (Ducke and Munch 2005: 105). These meanings are thought to be lost and not possible to reconstruct because further information required to elucidate these patterns are most likely to be passed on through, oral tradition and long-since lost to the vagaries of time (Ducke and Munch 2005: 105). On a larger scale, the landscape is also believed to be mentally transformed through religion, politics and tradition- the modelling of these transformation processes is thought to be an opportunity for future research (Ducke and Munch 2005: 105). They also believe that this human behaviour may be approximately modelled by examining the differences over time between real distribution and ideal distribution based on "suitability" estimations in areas where there is sufficient archaeological data (Ducke and Munch 2005: 105). An example of this can be seen if pre-Neolithic and Medieval sites are removed from the predictive model because both of these types of sites present a completely different form of land-use that can be seen from distribution patterns, that is, hunter-gatherer communities compared societies possessing trade networks (Ducke and Munch 2005: 105). In conclusion the researchers state their belief that the predictive model could perform at an enhanced level, by also fully taking into account social and cultural processes, but also state that this is probably not possible at present given the lack of supporting archaeological evidence that would be required to somehow measure these processes in any quantifiable manner, and to delve into this type of analysis entails an entirely new research effort (Ducke and Munch 2005: 105).

Thus, the implications of the Brandenburg project for developing a Harappan port site location predictive model are clear.

In terms of physical criteria, the model seems to favour value the nearness of non-saline water bodies both in terms of areas of higher biodiversity and as a transportation network.

For Harappan sites, nearness to water is obviously an issue, though in the case of a port or beaching area- a coastline, saline location is of, at least, as much significance for bulk, long distance trade.

The "suitability" model mentioned, in simpler language, appears to be the simple calculation of an average, representative site. In the case of the Harappan culture this can be seen, perhaps in a specific typology of structure, for example ports, dockyards or manufacturing areas and a typology of artefacts, for example, faience beads.

It is interesting to note, that many of the problems, as well as, in a broad sense, the methodology involved during the creation of the Brandenburg model, parallel the experiences during the development of the Harappan model. Since these models have been created in isolation, one may conclude that the process of site location modelling is somewhat standard in practice.

It appears that, in their experience, creating a site location model is time-consuming because it requires a quantity of data of verifiable quality obtained through thorough testing procedures. It should also be noted that the Brandenburg researchers have been involved in re-surveying some of the sites, in order to confirm the accuracy of the data previously obtained. This has, unfortunately, not been possible in this research, but it does re-emphasise the need for data quality in the model. An argument could perhaps be made that there is a certain unfortunate possibility and perhaps a requirement, for a duplication of effort if the data cannot be wholly trusted. This extra cross-checking stage obviously somewhat detracts from the initial usefulness of a site location predictive model as prior stage to fieldwork if, at the end of the process, no time has been saved. The Brandenburg team can, of course, be excused for this as the research is as much a test bed for predictive modelling methodology as much as a practical application. Thus, it is also the case here, where it is hoped to test the efficacy of predictive modelling as is stated in the project hypothesis.

Finally, although the Brandenburg team acknowledge the opportunities of modelling religious, political, social and cultural processes, they also emphasise the requirement for

greater temporal and spatial resolution of data has not been satisfied with the currently available archaeological data.

Part of the Harappan research is to attempt to model some of these aforesaid processes, though specifically those concerned with geographical theory, and the difficulties inherent in these efforts, both in formulating algorithms capable of modelling such intangible phenomena. The paucity of archaeological data has also been shared with the Brandenburg researchers.

1.7 Archaeological Predictive Models and Expert Systems

The focus of the research now turns to the use of Artificial Intelligence (AI) techniques (Copeland 2000) in predictive modelling, particularly the use of rules based expert systems which have been so prevalently used in past experiments with AI technology. This is useful to study because in order for models to do more than simply push numerical data through formulas, it is also possible to induce intelligent behaviour in the ability of models to produce useful results, thus, on occasion, it is thought useful to attempt the inclusion of some aspects of intuitive reasoning into models. This can be achieved by using techniques borrowed from cognitive science and AI.

This combination of machine intelligence and modelling is interesting given a paper from 2003 where the minds of children are thought of as a type of predictive model where children build models of the thinking, motives, moods of their parents and siblings as part of socialisation (Barsh and Chantelle 2003: 587).

What follows is a brief discussion of the use and relevance of expert systems to archaeological predictive modelling.

1.7.1 Why Use an Expert System?

With archaeology in general some data types lend themselves well to AI analysis techniques, more specifically, the use of expert systems.

There are various forms of expert systems, these can be described in AI terms as, a knowledge based forward chaining expert systems, where forward chaining simply means a data driven rather than hypothesis driven, or a backward chaining expert system with a top-down approach where the data is filtered through a set of rules.

Although expert systems have a reputation for brittleness when faced with input outside their narrow parameters and have been described as "idiot savants" (Fritz 2002: 24), as long as the data is already confined, narrow and within specific limits, this challenge can, in some instances, actually prove to be a benefit. The actual mechanisms of expert systems will be fully described later in this chapter.

It is also thought favourable to automate expert systems technology in order to further the ease of processing many different factors pertaining to site location. To manually process this information is a resource waste and the ability to apply the many archaeological rules to a large data set is an attractive proposition (Crevier 1993: 158).

1.7.2 How Does an Expert System Work?

An expert system uses data and (Covington 1994: 295) that is stored in order to infer an answer about a particular problem. This is in contrast to a database which simply retrieves data (Covington 1992: 125).

For the sake of an extremely simple test case, soil micro-morphology provides an apt example of a test case for expert system techniques in archaeology. Expert systems are usually interactive, that is, at their simplest they interact directly with the user through a simple question and answer routine.

Therefore in this example, there are basically two states for each deposition type in soil micro-morphology when relating it to the occupation level of a settlement in the model. These states are-

"Yes" or "No".

To further elaborate the point, this is an example of a program where the only questions asked are as follows and concern only two possible states for each type of deposition. First a table of questions is created for the program-

Is there primary cultural deposition? "Yes" or "No"
Is there secondary cultural deposition? "Yes" or "No"
Is there tertiary cultural deposition? "Yes" or "No"

A table of rules (McCallister 1989:14), also known as the rules base, forms the basic archaeological rules that tell the program what to make of the available data. In this example, a rule is defined that infers that if all three forms of deposition are present; then the site has seen more human activity than if there is only primary deposition. Thus, possible answers are also added to the program-

First only = Low
First two = Medium
All three = High

Finally, when the program is run, part of the program called an inference engine loops through the database applying the above rules to its search and performing an action when it finds one of the rules to be true-

Ask the user if there is primary deposition
Ask the user if there is secondary deposition
Ask the user if there is tertiary deposition
Depending on the final sum of answers infer a diagnosis

These skeleton pseudo-procedures may be easily be translated into any computer programming language with relatively few changes. There can, of course, be dozens of rules examining each data attribute and an inference engine to control the flow of all the database records through all the rules.

1.7.3 Overview of Expert Systems

Expert systems in science is not new and a very well known and particularly successfully tested, so- called "brittle", expert system is MYCIN, developed by the Stanford Medical Centre and a tool for diagnosing infectious disease (Horn 1986: 5). Unfortunately for legal reasons, MYCIN has never been officially implemented.

While expert systems in archaeology do exist, they seem used on somewhat a micro rather than macro scale. For instance, a brief web search turned up only one expert system. This is an expert system to identify coinage of the Coriosolites; one of several tribes in Brittany at the time of Caesar's campaigns in Gaul (Hooker 1996). Admittedly the reason for this might be that use of expert systems in archaeology is not well accepted of late. As one researcher comments-

> "I would suggest that archaeological predictive modelling falls short as a candidate discipline for the application of an expert system. While some elements of archaeological predictive modelling, such as use of GIS, follow more or less formalised procedures, the expert knowledge that is required to solve an archaeological problem is for the most part neither explicit nor accepted." (Dalla Bona 2005: 199).

This has not always been the case though. During the 1980s, Professor Jean-Claude Gardin led a group of archaeological researchers in France in an effort to use expert system technology to assist in solving archaeological problems (Gardin 1988: 12). The objective of the project was also partly for the purpose of determining whether expert systems, particularly in the field of the humanities; a less precise field of studies than the science of mathematics, could benefit from the application of expert systems (Gardin 1988: 12). Six systems have been constructed using the SNARK and ARCHES expert systems; the overall conclusions were that generally the expert systems do not fully meet expectations, however, the very action of building expert system helped the archaeologists formalise the logic of their assumptions (Lauriere 1988: 9).

One other example, interestingly, conforms to many functions required in this research. The system was one designed with the purpose of deciding whether an excavated site can be identified as a medieval fortified garden, this application worked relatively well, though only at a simplistic level (Zadora-Rio 1988: 166).

A more recent example can be seen from an attempt to create a system for pottery classification (Kampel and Sablatnig 2007). Here, data is run through a table of rules created by examining human expert knowledge of the subject area (Kampel and Sablatnig 2007: 740).

The system eventually designed for this research most closely resembles, in intent rather than function, an older system used by a geological prospecting company, it was a system called PROSPECTOR (Duda 1974-1983). Although not built for archaeology, this system was a site location program for mining that has successfully found ore deposits where land-based surveying and remote sensing had previously failed (Horn 1986: 10). It was used by knowledgeable users, in this case geologists, and worked by basing its search assumptions on past characteristics favourable to mineral exploitation (Prospector 2006). As this system seems most similar, in purpose, to the type of system required in this research a detailed case study of the PROSPECTOR system follows.

1.7.4 Case Study, Site Location Expert System: PROSPECTOR

In their article to Science in 1983 Richard O. Duda and Edward H. Shortliffe, principal developers of PROSPECTOR- a site location program for mining and MYCIN- a medical diagnostic system respectively discussed their experiences. This case study will concentrate on PROSPECTOR, as it is this particular system which is of most interest to this research.

They state, in the article, that AI has long been a topic of basic computer science research and is "now being applied to problems of scientific, technical, and commercial interest" (Duda and Shortliffe 1983: 261). They go on to state that, although some of these applications are limited, they have gained some success rivalling those of humans and that

one of the benefits of this research is the systematisation of previously un-formalised knowledge (Duda and Shortliffe 1983: 261).

Although, at the time of writing, they refer to their own specific research, there is no reason why this should not be applied to other sciences, particularly where the concepts of predictive modelling for site location so closely matches systems like PROSPECTOR.

They go on to discuss the historical background of the formalisation of scientific knowledge, the goal of which is to "obtain quantitative descriptions of natural phenomena" because anything that cannot be measured empirically leads to a limited understanding (Duda and Shortliffe 1983: 261).

They believe that AI, and, particularly, expert systems are a set of tools and concepts that allow the aforesaid formalisation of scientific knowledge and, fortunately, with the advent of the digital computer, serious AI work can begin in this area because, apart from being calculating machines, digital computers can be tasked for general-purpose processing and programmed to support intelligent behaviour (Duda and Shortliffe 1983: 261).

With this in mind, they state that researchers have written programs to solve well-defined problems that have distinctly non-numerical characteristics, for example, programs that, amongst many others, can, play games, solve puzzles and prove simple theorems in algebra and geometry (Duda and Shortliffe 1983: 261).

What has arisen from this early research are general methods for representing information in symbolic data structures and general methods for manipulating the data as well as querying it (Duda and Shortliffe 1983: 261). These results supported the possibility, in theory, of machine intelligence, but fell short of providing solutions for developing programs that could solve complex practical problems (Duda and Shortliffe 1983: 261).

Initial enthusiasm later declines when it is realised that these techniques cannot, given the state of technology at the time, and, even to this day, generate intelligent behaviour (Duda and Shortliffe 1983: 261). Basically, this is because it is difficult to code a program to intelligently deal with any complex situation because general problem-solving techniques

are confronted with imprecisely stated problems, uncertain facts and unreliable axioms (Duda and Shortliffe 1983: 261). The reasons for this are that humans possess knowledge of which the programs are not aware. That is, the machines have incomplete knowledge (Duda and Shortliffe 1983: 262). This has led to a paradigm-shift in AI. The fundamental problem of understanding intelligence is not the identification of a few powerful, all-encompassing techniques, but the question of how to represent large amounts of knowledge in a manner that allows their effective use and interaction (Duda and Shortliffe 1983: 262).

Thus, AI has shifted from a strategy of developing a machine intelligence to a knowledge-based approach (Duda and Shortliffe 1983: 262). This is what is meant from the term "Expert Systems" and the development of expert systems programs is one of the results of this paradigm shift (Duda and Shortliffe 1983: 262). This is a much simpler and more productive approach because rather than trying to write programs that emulate human perceptions or common-sense deductive reasoning, it has proved much easier to emulate the problem-solving methods of some types of experts with specialist knowledge in a particular field (Duda and Shortliffe 1983: 262). This is because many human experts are distinguished by their possession of extensive knowledge in a narrow field of study (Duda and Shortliffe 1983: 262). And it is this very limitation that makes it possible to provide a computer program with sufficient knowledge so that it can perform those tasks of analysis effectively (Duda and Shortliffe 1983: 262).

The simplest and generally most successful expert systems are thus, classification programs designed to be used in a well defined topic area; their purpose to weigh and balance evidence and to decide how it should be categorised (Duda and Shortliffe 1983: 262).

And thus, it is that the PROSPECTOR system for geological mineral exploration consultation is designed for problems in regional resource evaluation, ore deposit identification, and drilling site selection (Duda and Shortliffe 1983: 265). The knowledge base is organised around models of different types of ore deposits, along with other notable expert system such as MYCIN, PROSPECTOR has an incomplete knowledge base, however, in tests with data on known deposits, PROSPECTOR assessments are repeatedly

agreed to closely match the opinions of the geological consultants who provide the models (Duda and Shortliffe 1983: 265). In other words, once operational, PROSPECTOR, independent from those human experts whose opinions and expert knowledge form the basis of its knowledge base, can make judgements that mirror those experts (Duda and Shortliffe 1983: 265).

In fact, there is one case of a test involving a current exploration project where, PROSPECTOR accurately identifies the location and extent of ore-grade minerals for a previously unknown portion of a molybdenum deposit (Duda and Shortliffe 1983: 265). While this is not a formal statistical study, its success justify extending the PROSPECTOR knowledge base further (Duda and Shortliffe 1983: 265). Therefore a common characteristic of PROSPECTOR and other systems such as MYCIN are that their knowledge bases are incomplete (Duda and Shortliffe 1983: 265). The identification and encoding of knowledge is one of the most complex and difficult tasks encountered in the construction of an expert system, however, the very effort to build a knowledge base often discloses gaps in understanding of the subject domain and weaknesses in ways of representing this body of knowledge (Duda and Shortliffe 1983: 265).

The authors go on to note the extreme difficulty of creating such expert systems at the time of writing. They state that even when an adequate formalised knowledge has been developed, experts often have difficulty expressing their knowledge in that form (Duda and Shortliffe 1983: 265). Thus, the process of building a knowledge base usually requires a time-consuming collaboration between a person with expert knowledge about a particular topic and an AI researcher (Duda and Shortliffe 1983: 265). And while an experienced team can put together a small prototype system in, perhaps, months, the effort required to produce a system that is ready for serious evaluation is often measured in years (Duda and Shortliffe 1983: 265).

They finally conclude that it has been suggested often that some kind of learning process might solve this problem and that a related idea is to provide the human expert with an appropriate way to "teach" the system directly (Duda and Shortliffe 1983: 266). While both of these ideas are thought to be plausible, programs that can learn or be taught seem to need a significant amount of technical initial knowledge, together with mechanisms for

assimilating that knowledge properly and although this is an idea for future research, learning techniques cannot solve the problems facing the builder of expert systems (Duda and Shortliffe 1983: 266).

The forbidding thought that the design of expert systems can take an inordinate amount of time to develop, however, should not deter its use. It must be remembered that at the time of writing, the tools available to Duda were far less sophisticated than those that are available today. Also the very knowledge of expert systems techniques is far more widely disseminated. One very valid point they make, however, is that formalisation, such as in this research where it is meant- the formalisation of archaeological knowledge, is needed for the model being considered to succeed.

1.8 Advantages and Disadvantages of Archaeological Predictive Modelling

Finally a brief examination of both some of the main advantages and disadvantages to predictive modelling as a whole follows

1.8.1 Data Completeness

If the data is complete in every aspect then all predictive modelling can achieve is mere confirmation (Woodman and Woodward 2002: 23).

Where the data is incomplete, as is the case with much of archaeology, predictive modelling can be applied. Although the results will, of course, be suspect to question, the act of modelling may assist in revealing new patterns in the data not yet apparent from previous research.

1.8.2 Archaeological Processes

The case that predictive models do not fully encompass the archaeological process.

This is more a criticism based on highly environmental based models (Woodman and Woodward 2002: 22). If other factors are taken into account, such as the inclusion of various geographical and other theoretical approaches, this criticism can be somewhat refuted. Also while this point of view may be valid, it is not always possible to conduct direct, physical research in the form of fieldwork for many research efforts including this one where there are difficult political ramifications, as well as the bureaucracy and differing national laws and permits to navigate. One might also consider, as touched upon in the previous point, that information gathered from non-destructive data collection is sometimes also not sufficient or even available. This is also the case in this research where there is no aerial photography available for the area. Thus, predictive modelling can and should be used as simply another archaeological tool.

As predictive models can be thought of as only part of an archaeological iterative process. The aim of the entire process is to develop knowledge into the past, in terms of peoples relationship with their environment (van Leusen and Kamermans 2005:7).

1.8.3 Predictive Models as Simulations

Archaeological predictive models can be described as mere simulations of reality too far removed from the original base data or human interaction. Predictive models, particularly those created for use in archaeology, are however models and like all models, they are, by definition, simulations of reality and not reality itself. Therefore models are all prone to an oversimplification of complexity.

However, this so-called, "reductionism" is the very essence of how human-beings make sense of the world around them. Human vision, for example, can only see certain parts of the spectrum, while the vision of some other animals is stronger in other parts of the

spectrum. Which then is the true visual representation of objective reality? Thus, it can be argued that such a reductionist stance, helps in the identification of patterns (Woodman and Woodward 2002: 22) and trends in the underlying data. To surmise, models simplify complex environmental and human systems into more manageable and categorised units.

1.8.4 Accuracy

Some successful site location models are only reported as being up to seventy percent accurate (Ebert 2000:133).

This level of success is not particularly low and predictive modelling can thus be valuable as a time-saving tool for often under-funded and under-resourced archaeological teams.

1.8.5 Computational Power

Models suffer from lack of inexpensive and powerful computer hardware and software, in other words computational power.

Researchers using predictive models can now take advantage of the major advances in computer technology. For example, with the advent of Relational Database Management Systems (RDBMS), the evolution of simple computer scripting languages with powerful data extraction tools and increasing computer processor power, there is more reason than not, to use these tools in the quest to build better models.

1.8.6 Skill-Sets

This over-reliance on physical or environmental data is indicative of the current skill-sets of most archaeologists.

However, one need only see that in-roads are being made, though slowly, as in the example of the fjordland study described before (Mackie 1998). Even in the past, there are examples of the desire to extend the data-set and the goals of traditional modelling past the merely physical, descriptive and CRM based usage. Michael Jochim (Jochim 1991) makes the point in his article *Archaeology as Long-Term Ethnography*, that in order to develop a more in-depth understanding of archaeological processes there is a need to use, amongst other tools, GIS and modelling as they offer the "potential for analysing such complex patterns". He goes on to say that it is necessary for the full utilisation of these applications that archaeologists "should include more than natural variables of topography and watercourses, which are presently emphasised" (Jochim 1991: 318).

1.8.7 Data Quality

While it is, of course, impossible to obtain perfect and complete data covering every single aspect of the sample sites it is, however, vital that model-builders have access to relevant, clean, detailed, complete and, above all, accurate data in order for their predictive models to generate useful location data. The old computer adage applies here– "Garbage In - Garbage Out" (GIGO).

1.8.8 Model Context

It should also be remembered that the models, once built and running, only represent hypotheses to be tested in an archaeological field-survey and are not the end product of the research (Moon 1993:15).

1.8.9 Predictive Models as a Budgetary Tool

Another point to make about the relative advantages of modelling concerns budgetary considerations. It should be reiterated here that predictive modelling can be used as a basis for developing a project proposal which depends on the accuracy and validity of the model.

1.8.10 Predictive Model Use in Other Fields

There is also the case that models developed for archaeology can be useful in other fields as well as CRM. For example, highway-planning or where large development or disturbance of the landscape is being considered and archaeological conservation or investigation must be taken into account (Podobnikar et al 2000: 544).

1.8.11 Better Models Through Trial and Error

A final point to make on the subject is that if no other archaeological research is attempted in experimentation with predictive modelling for site location, that is, by the development of good as well as bad models then the science of predictive modelling will stagnate completely. In other words, the very practice of building and testing models is in itself a way of improving and extending the techniques and practice of a fairly misunderstood field. If this occurs than the many small successes accrued in this branch of archaeology will be wasted.

1.8.12 User Expectation

Predictive models of all types are not always well received and can be controversial. Wheatly states that there is an argument that correlative predictive models for site location have not been successful because they are separated from wider theoretical concerns within archaeology (Wheatly 2004: 5). This statement appears to imply that problems can occur if predictive models are thought, perhaps short-sightedly, to not reveal information currently deemed to be of importance by the archaeological mainstream. An alarming example, of the dangers of what perhaps can be called "domain demarcation conflict" is the case of Dr. Kim Rossmo (Rossmo 2009), a police officer and geographic profiler who in 1998 informed his superiors of a trend he had discovered of missing women that he thought could be the work of a serial killer, ignored and later dismissed from service (Hall

2001), he has been subsequently, and tragically been proved correct (MacQueen and Macdonald 2007).

1.9 Building an Archaeological Predictive Model

The actual physical substance of the model itself varies greatly depending on the subject in study, the availability of tools, as well as the experience and knowledge of those designing it. One of the most common ways of producing a site location predictive model is through the use of a Geographical Information System (GIS). This is at its most basic a Database Management System (DBMS) that can store data and that also includes a map component (Moon 1993: 15).

There are many steps in building an archaeological predictive model, but perhaps there are three main stages that are the most important.

The first is to identify attributes that will be included in the model. The most important part of this stage is to identify relevant attributes whose data will be obtainable in sufficient quantity and quality. These attributes can include data from many sources, for example, traditional archaeological data such as deposition types, artefact typology, radiocarbon dates as well as data from meteorology, natural resources and geographical extents.

The second is to find the data for the selected attributes. The first and second stages may be iterative or cyclic depending on data availability. The source of this data can include archaeological records, soil data, remote sensing data, historical maps, topography, geology, environmental and ecological data as well as other information. Data should be then evaluated on its relevance to the model in question. The modeller will also need to hypothesise as to the types of site that are expected to be found (Altschul 1988:80).

And the third is to decide on what algorithms or formulae to perform of this data. The calculation methodology chosen should be meaningful, both in terms of producing visible and identifiable trends and not overly complex in order to minimise errors. It should be noted here that although the choice of language used here suggests that these models only

process numerical data through use of various statistical methodologies, this is not always the case, for example, the use of pattern recognition algorithms that process graphical data. One should also take into account that other theoretical approaches that may be converted via a formulaic analogue for use in the model. For instance, the various economic and urban models used in geography, for example, Central Place Theory of Walter Christaller.

After the model is operational, there should be a trial or testing period in which the model is tested for its ability to find one of the representative sites. The test should be blind, in this case that would mean one of the most representative sites should be removed from the model. The model is then run and, if all proceeds according to plan, the model should predict the location of this removed site. In this way the model can be fine-tuned, perhaps by changing some of the attributes used or verifying data quality.

It is important to note that the site location model should not solely utilise existing representative sites as the only data set used in the analysis. All possible sites should be present including locations where there is unlikely to be a new site. This is because negative prediction is also a valuable aid in site location models enabling archaeologists in the field to ignore certain areas for further exploration, at least until the more favourable possibilities have already been investigated. Therefore, it is also necessary to be able to obtain sound environmental information describing locations of where sites are not likely to be found. (Moon 1993: 7).

Also site locations should not use a narrow or very limited set of attributes. For example, an attribute such as "distance to water" might be meaningless on its own as there are almost certainly many non-site locations the same distance away from water, whereas if "distance to water", "sheltered location" and "aspect" are considered together, they may hold a much higher degree of significance. Whatever the case, it must always be remembered that predictive models are highly prone to the subjectivity of the designer. However, this same subjectivity can also be a benefit by using the subjectivity of expert opinion to weight algorithmic results.

1.10 Summary

The are many types of predictive model in use in site location applications, many share similar traits and while some are based on comparisons on highly subjective experiential data, other use mainly fact based approaches. There has also been some success in locating sites using AI techniques such as expert systems.

Predictive modelling is useful where data is sparse, though direct excavation may be more successful in terms of reliability.

Building a predictive model is a multi-layered process involving GIS, databases and all the associated data collection and data processing procedures.

1.11 Conclusion

While examining archaeological predictive modelling in general it becomes apparent that there is no "off-the-shelf" software available for general, multiple environment site location. Most predictive models used today are proprietary, non-portable systems consisting of non-automated manual procedures combined with the use of statistical software, spreadsheets and GIS. In other words, each research team creates their own unique models that can only be used for that particular research. Thus, one useful aspect of this research can be to attempt to propose the production of a simple, "off-the-shelf", predictive model program for site location based on the experience of developing the HPPPM. Any such future system should also, hopefully, be flexible in terms of culture, period, geography and other factors.

It is also obvious from the opinion formed by Ford, during his research in Maryland (Ford 2007), that the sole use of predictive models is not sufficient for accurate results. It should be noted though, that Ford has relatively easy access to the sites in question and the possibility of fieldwork, therefore, he is not as reliant on modelling as this research is reliant on the HPPPM.

Predictive modelling is, at present, more of a conceptual set of techniques rather than a simple tool that any archaeologist can acquire, ready-made and simply use. The main reason and, herein lies the main criticism of predictive modelling, is that in order to be accurate, the models need to be specific and narrow in scope. However, it can be argued that the model needed in this research should be general in its design, but specific in its actual use. By this it is meant that the model should be able to incorporate the views of, for example, a knowledgeable archaeologist who is an expert in Harappan Civilisation into its rules base or be a tool that allows the opinion of a learned user, in terms of their manual analysis of the results.

Since the proposed predictive model requires data there will now commence research into the main defining features of most Harappan sites.

2. Harappan Civilisation

2.1 Introduction

This chapter will briefly describe the discovery of the Harappan Civilisation, its extent, the history of the region from the Pre-Harappan to post Harappan times, some of the more important sites and the main distinctive features of this culture. This should enable the formation of a broad overview of the Harappan period and culture and also act as an introduction to the a detailed study of trade and exchange. This is important because the predictive model is intended to identify salient features of ports and thus, subsequently, build a picture of maritime trade networks in the region.

2.2 Discovery

What follows, therefore, is a brief account of the discovery of the Harappan Civilisation.

In 1829 James Lewis, a rather colourful character, travelling under the pseudonym of Charles Masson, was the first recorded European to visit Harappa on his way to the Punjab after deserting the Bengal European Artillery- a regiment of the British East India Company army (Lahiri 2006: 4-5). Then in 1831, another deserter, Richard Potter, travelling under the name of Alexander Burnes visited Harappa after mapping the Indus River (Lahiri 2006: 4-5). It is not so surprising that no professional archaeologists have been involved in the initial uncovering of this civilisation until much later because at the beginning of the twentieth century, in the Near East, archaeology tended to be the domain of the informed amateurs such as surveyors, architects and engineers involved in the practice cartography and exploration (Kouchoukos 2001: 80).

The activities and reports of these early adventurers, one assumes, eventually came to the attention of a former member of the Bengal Engineers regiment- Sir Alexander Cunningham; appointed the first director of the Archaeological Survey of India. He visited the site twice, once in 1853 (Lahiri 2006: 17) and then later in 1872 (Lahiri 2006: 18).

However, by the time of his second visit much damage had been done from the removal of bricks used to build the bed for the Lahore-Multan railway in what is now Pakistan (Lahiri 2006: 18). He concluded that the material probably related to the ruins of nearby 7th Century AD Buddhist Temples. Although, not realising the true antiquity of the site (Fairservis 1975: 250), minor excavation did follow with some pottery, carved shell and a seal depicting either a one horned bovine animal, or, more likely perhaps, the side-profile (Marshall 1931: 68) of a more probable two-horned animal with only one horn showing; one of the so-called "unicorn seals". No more work was carried out until the early 1920s.

The first real indication that there is a civilisation rivalling that of Ancient Mesopotamia and Egypt comes during trial excavations during which Sir John Marshall, the second director general, appointed Indian archaeologists to work at various sites. This included R. Sahni at Harappa in 1921, D. R. Bhandarkar at Mohenjo daro in 1911 followed later by R. D. Banerjee in 1922 (Possehl 1999: 47-62).

According to noted Harappan scholar George Dales, the Harappan Civilisation of Pakistan and western India is thought to be the earliest examples of an urban culture in South Asia (Dales 1973: 3). Later excavations have shown that this culture encompasses many other rivers and extends to a wide area over what are now modern north-western India and eastern Pakistan. Satellite imaging (BBC, 2002) has also revealed that the previously thought mythical Saraswati river, perhaps, flowed along the side of some the settlements of this culture. Its mature, developed period lasted for very approximately five hundred years between c. 2400 BC to c.1900 BC.

This new discovered culture eventually became known as the Harappan Civilisation in order to de-emphasise what early archaeologists thought is a civilisation solely geographically linked to the Indus River and also to remove the false assumption that the Indus Valley Civilisation was a superior, non-Indian culture. Today, the terms "Indus Valley Civilisation" or "Harappan Civilisation" are interchangeable and largely free of imperialist or anti-imperialist sentiment. For the sake of consistency, as stated before, the terms "Harappan Civilisation" or "Harappan Culture" will be used in this research.

2.3 Extent

Wider excavation in India, that started after the independence of India and Pakistan and still continues sporadically today, by mainly American and Indian universities, has revealed that there are, at the current count, possibly over a thousand Harappan (Lawler 2008), or at least Harappan related unconfirmed sites (Possehl 1999: 727-835) spanning modern Pakistan and North-West India and other major rivers, deltas and coastal areas. The major rivers include the Indus, the Saraswati and the Hakra-Ghaggar and their many tributaries. It should be stated, however, that there has been some recent debate as to whether this can be classified as a single civilisation over the entire region or if areas within, such as the Saurashtra area of the Gujarat in particular, were separate entities. This theory has been expounded most publicly by the Indian scholar Professor Vasant Shinde of Deccan College (Kapoor 2007). To further complicate matters, in the year 2000, the discovery of a hoard of Harappan jewellery in Uttar Pradesh around one hundred and fifty kilometres east of New Delhi; shows that this civilisation is spread over a much greater extent than has been previously thought and demonstrates that the culture is not merely centred in eastern Pakistan and western India (Maneesh 2000).

Therefore, although at one time, the Harappan Civilisation, has been seen as an isolated entity, existing in splendid isolation, it is now seen to have occupied a much wider geographic area than only the Indus Valley and to have had strong trade links to the west at the time of its conception and is said to have, at least some influence to the east during its decline, on the Gangetic civilisation that succeeded it at around 1000 BC. It is, therefore, "no longer regarded as something imported into India solely in the chariots of Aryan invaders" (Kirk 1975: 19). In fact, one could say considerably more on the subject of this presumed splendid isolation of Old World cultures, particularly those of the Harappans and Mesopotamians; T. F. Potts comments that to regard Mesopotamia and the Harappans as isolated locations of early urban developments, separated by uncivilised highland areas is no longer a viable hypothesis (Potts, T. F. 1993: 379) and the evolution towards urban settlements is purely indigenous (Dales 1973: 4).

This distribution across Pakistan and India makes it the most geographically extensive of all ancient civilisations thus discovered. Far larger, in fact, than both Egypt and Mesopotamia together. It is said to be spread over an expanse approximately twice the area of Mesopotamia (Whitehouse 1977: 121, Kenoyer 1997:3). One measurement suggests that it covers an area of approximately one million square kilometres (Possehl 1999: 157). Even the area where the civilisation is supposedly centred, the greater Indus Valley ranges over a triangular area of approximately two thousand five hundred kilometres (Dales 1973: 3).

The civilisation also covers a diverse geography. Most relevant to this study are the long expanses of coastline with numerous inlets (Chakrabahti 2004: 29) that seemed to thread through and encompass the whole of this culture.

Subsequent to further study during the course of this research, a map has been produced with various ArcView layers, exported to a photographic manipulation suite (see 5.5.5 Graphics Manipulation Programs) and a scaled map produced. For the sake of clarity, it should be noted that this map omits some of the site names though these can be seen on in another map (see Figure 5.1 Possible Port Sites in the Gujarat). The scale has been composed by superimposing an ESRI shape-file over and standard scale map of the area. Thus, the map that follows, space and data sources permitting, shows the sites in terms of topography, that is some spot altitudes for sites are included, as well as site, region names and their modern geopolitical context.

Figure 2.1 Detailed Map of Research Area

As can be seen, this is and area of crenelated coast-line, navigable rivers, inlets, estuaries and projection into the Arabian Sea which offered the Harappans access to other cultures such as Mesopotamia to the west and made this region an ideal location for Harappan settlements involved in maritime trade. Therefore, hypothesis testing in this arena may assist in further interpretation of archaeological questions in this least researched Old World Civilisation.

2.4 A Brief History

First, a very approximate contextual chronology of the Harappan Civilisation is attempted by examining, in brief, the general place of Harappan culture within the larger framework of the Old World Civilisations and what events were taking place elsewhere to gain some semblance of historical perspective-

c.1600-1000	Early Vedic Period of the Hindus (Encyclopaedia Britanica 2009)
c. 1600-1500	Apocryphal Aryan invasion of Indus Valley (Kenoyer 2003)
c.1792-1750	Hammurabi's Code of Laws, Babylonia (Rowton 1958: 111)
c.1900	Start of decline of Harappan Civilisation (Kenoyer 2003)
c. 2300-2000	Exchange between Harappans and Mesopotamians
2400 BC	Harappan cities established
c.2500	Khufu's (Cheops) Great Pyramid
2500 BC	The Mature Harappan period
c.2600	Harappan Civilisation begins (Kenoyer 2003)
c.3100	Menes and the First Dynasty of Upper and Lower Egypt
4000 BC	Fortification of larger communities
6000 BC	Large farming villages on the Indus Plain
7000 BC	Pre-Harappan Mehrgahr agricultural village in Baluchistan

Over the years Harappan chronology has been subsequently revised and refined by Kenoyer and others (Kenoyer 1997: Table 1, Kenoyer 2002: Table 1, Possehl 1999: 450, Possehl 2002: 66, Belcher 1997) and the approximate periods, based on the work at

Harappa and Mehrgarh, can be surmised as follows and give a general guide for dates of the Harappan culture as a whole-

1800	to	1500 BC Late Harappan Post Urban Phase Cemetery H (Period 5)
1900	to	1800 BC Late Transitional Harappan Mature to Post Urban Phase (Period 4)
2200	to	1900 BC Late/Final Mature/Urban Harappan Phase (Period 3C)
2450	to	2200 BC Middle Mature/Urban Harappan Phase (Period 3B)
2600	to	2450 BC Early Mature/Urban Harappan Phase (Period 3A)
2800	to	2600 BC Early Harappan/Harappan Transitional Kot Diji Phase (Period 2)
3300	to	2800 BC Early Harappan Ravi-Hakra Phase (Period 1 A and B)
7000	to	4500 BC Pre-Harappan Mehrgarh agricultural village

In an attempt to clarify matters of chronology, in the light of recent research; phases, dates and events have been assembled into a diagram that can be seen overleaf.

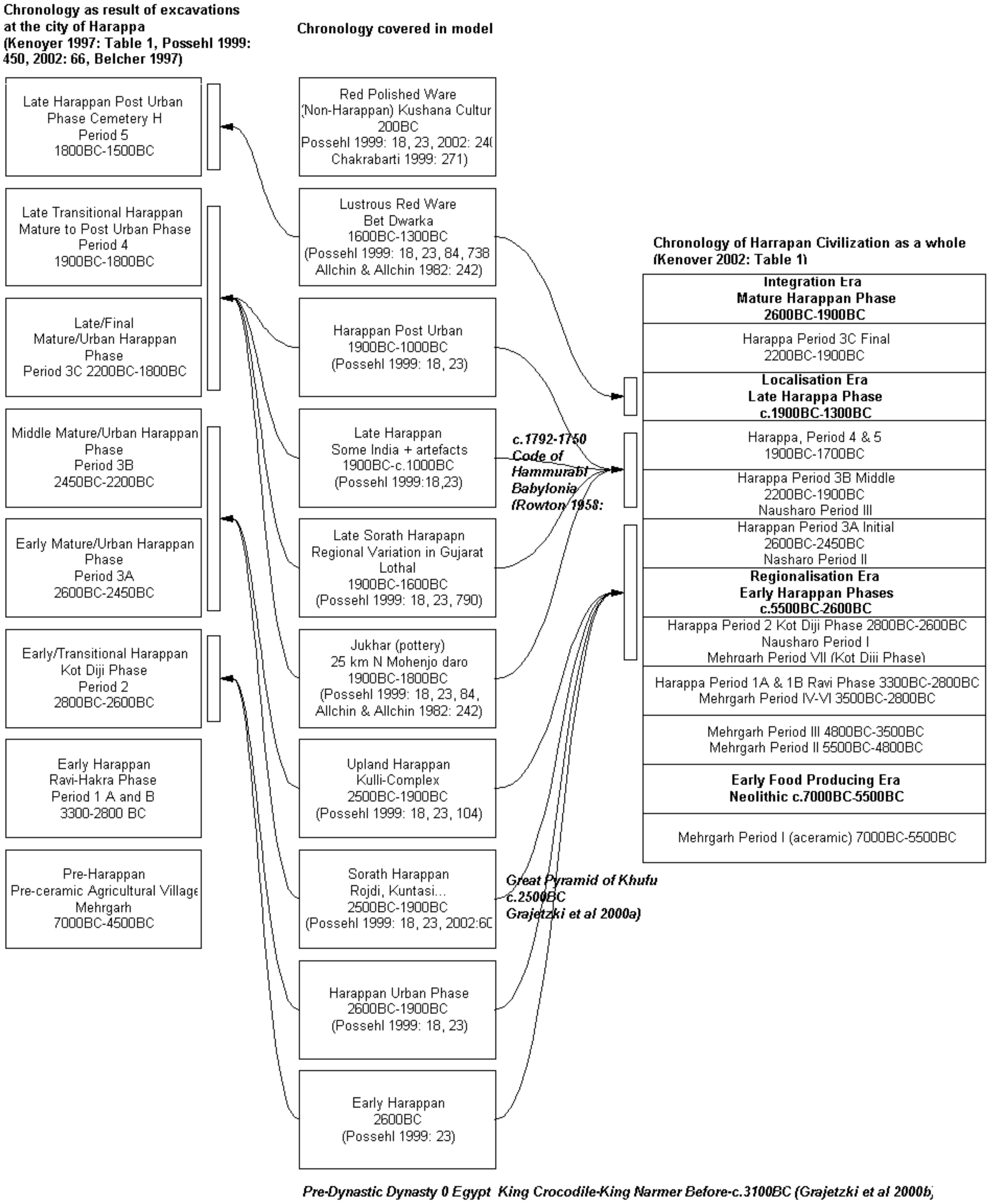


Figure 2.2 Harappan Chronology

Regarding Figure 2.2 as complicated is somewhat unavoidable in that the dates may have been rearranged over the years to tie in to what is known about the chronologies of other cultures; in the case of Harappans this has usually meant an attempt to find correlations between Harappan and Mesopotamian relative sequences as well as absolute dates (Reade 2001: 27). Despite these difficulties, not an uncommon situation in archaeology, it must be remembered that the Post-Urban phase in no way implies that the various sites are abandoned immediately, for example, Lothal is thought to have remained in use until the 1700s and although it is probable that loss of Mesopotamian trade may have affected the later Harappan Civilisation, it must be remembered that the culture is important in its own right and is not a culture wholly depending on is links to the west (Reade 2001: 28).

Each major period will now be discussed, from what came before, followed by the main events punctuating the history of Harappan Civilisation, what happened during its gradual decline and, finally, its probable evolution into a proto-Gangetic culture, shortly proceeded by the historic Vedic period. It should be noted that the dates of the Harappan Civilisation are somewhat approximate given slightly differing opinions on the exact duration by varying scholars (Brunswig 1973: 545-546).

2.4.1 Pre-Harappan

The first Palaeolithic sites of the region can be found in the Rohiri Hills, an eroded limestone plateau, surrounded by the Indus River alluvial plain in the Sind province of Pakistan (Biagi and Cremaschi 1988: 421). The picture of climate and landscape during this period ranges from humid and warm with some weathering at the Early to Middle Pleistocene to aridity and sand dunes during the Upper Pleistocene (Biagi and Cremaschi 1988: Table 1).

Approximately.9000 BC marked the end of the Ice Age and the beginning of the current Holocene epoch. During this time, hunter-gatherers in this region did not practice cultivation or build permanent settlements and all that they have left behind are a few scattered microliths; this is very different from the rest of western Asia where village-based hunter-gatherers can be seen and there seems no gradual transition from the Palaeolithic to

the Neolithic (Mithen 2003: 408). It is possible of course that the evidence for this transitional period is yet to be uncovered, or is simply that current chronological examination in archaeology is inadequate (Joachim 1991).

At around 8000 BC the first peoples arrived on the Indus plains via, perhaps, the Bolan Pass from western Asia (D'Andrea, 2003: 10). They settled to become small farmers; this is the precursor for the first agricultural settlements and from c.7000 BC to c.4500 BC settlers from the Bolan Pass, over the next few thousand years, built an agricultural village called Mehrgarh- the first such Neolithic village in South Asia (Chakrabarti 1999: 120-126, Possehl 1999: 450).

2.4.2 The Rise

The rise seems to have occurred for the most obvious of reasons- good farming land. Along with many small rivers, the huge Indus and other rivers flowed through the ancient landscape creating fertile alluvial plains from yearly silt deposition. There were also dense forests which, along with smaller animals, were able sustain large game such as elephants, water buffalo, rhinoceros, various deer species, pigs, humped cattle and tigers. And, although the issue of the transition to an agricultural society is a complex matter and largely outside the scope of this research, the least that can be inferred is that the transition in this region was in part due to the prevalence of potentially rich agricultural land. Along with this bountiful environment, however, the peoples of this time and region had to contend with yearly inundation and drought cycles, and necessity being the mother of invention, they eventually did this by becoming experts in the control of water (NHK 2000). However natural the rise may seem, it is noteworthy in that it is an extremely fast transition to an urban society taking only approximately one hundred to one hundred and fifty years (Possehl 2007: 261).

2.4.3 The Fall

Various theories accounting for the eventual collapse of the Harappan Civilisation have been put forward over the years. Everything from invaders from the north; the Aryan invasion theory of Friedrich Max Müller now out of favour (Lal 2005: 50-74), to over-exploitation of natural resources (Possehl 1967: 32, 38) or erosion and poisoning of the land by rising salt levels due, in part, to over-irrigation (Chew 2001: 35, Hewitt 1977: 358). Other environmental catastrophes such as the demise of the Saraswati and the changing course of other rivers as well as climactic change might also have been a factor. In fact, South Asian palaeoenvironmental data in the form of pollen cores from Rajasthan seem to indicate increasing aridity of the Indus area by c.3500 BC (Shaffer and Lichtenstein 2005: 84). It may be the unfortunate fact that the Harappans built their civilisation in a region experiencing only a short and temporary period of humidity in what is a largely arid landscape (Allchin and Goudie 1971: 248).

The Aryan invasion theory has been used by some scholars to tie in events of the Sanskrit Rg Veda that supposedly documented this invasion. There is no real evidence pointing to this (Sharma 2002: 10), however, and this seems to be the product of trying to make a religious text fit the archaeology. Biblical scholars have tried to do the same for years with the archaeology of the Near East and, while the Bible is a valuable historical document, it is also a highly subjective story and almost certainly not solely the domain of facts. Another problem with using religious texts is that the chronologies of these documents have not been fully confirmed and are at best relative, rather than absolute.

Also, one should take into account the political sub-context of much of Harappan archaeology in that there is some component of nationalism with both sides of the Indo-Pakistani border competing to be more "Harappan" than the other and thereby raising its profile as the country most likely to be one of the "cradles of civilisation". However, politics and religion aside, most scholars today seem to attribute a combination of environmental factors to the slow decline of the Harappans.

Other theories of the decline have also been expounded such as a decline in trade (Allchin and Allchin 1997: 212). Given the importance of the consideration of trade to this research, it is particularly interesting to note the Allchins view on the decline. Their opinion is that various factors may have led to abandonment of Harappan Civilisation sites including the decline in trade with Mesopotamia after around 2000 BC (Allchin and Allchin 1997: 212). They believe that this must have had a significant impact to the Harappans because along with the loss of such a major partner, there is no possibility of turning to alternative sources of trade as Mesopotamia and Egypt were able to do (Allchin and Allchin 1997: 212).

Archaeology is, in fact, full of such societal collapses, examples from the Old World include the hunting and gathering Natufians of c.10,000 BC to the later collapse of Urukian society at c.3000 to 3500 BC; both may have suffered at the hands of climactic changes in the form of severe droughts (Weiss and Bradley 2001: 609 to 610, Weiss et al 1993). Perhaps then, climactic, in combination with trade and possibly other natural processes eventually led to the winding down of the Harappan culture. This view is supported by a researcher at Ben Gurion University in Israel who believes that Early Bronze Age cities in Canaan also collapsed around the same time as the Akkadian cities due to drought (Abate 1994: 517).

Even from the earliest days of Harappan research, theories on the decline of the Harappans have tended to cause dissent. The short duration of its main periods of urbanism have been substantiated quite early from evidence of geomorphological and hydrological studies as far back as the 1960s which postulated flooding as a result of earthquakes (Raikes 1961: 297). Countering this position, for instance, it has been argued that the great tectonic disturbance theory that is supposed to have caused the decline of Mohenjo daro (Lambrick 1967: 494) by flood (Lambrick 1967: 485) when subjected to critical appraisal by Labrick in 1967 is thought to have rested upon insufficient evidence. He goes on to state that supporters of the theory claim that it is hydrologically and archaeologically acceptable and that further research should be based on it, though it is the belief of Lambrick that there may be a need for greater objectivity in the search for data and for fresh thinking (Lambrick 1967: 494). Thus, although the conclusions reached by earlier archaeologists

are now questioned in the light of what is currently known, it is thought that the Harappan Civilisation did not vanish suddenly; rather it degraded and, perhaps, transformed slowly.

Concerning the difficulties in proving a continuity into the Post-Harappan age, Sharma believes that the important elements of the Harappan culture completely disappeared by 1500 BC, in terms of the Indus script, fired bricks, large buildings and bronze and, although bronze objects appear in some sites in the states of Maharashtra and western Bihar in c.2000 BC, they are mostly absent in post-Indus cultures until c.1000 BC (Sharma 2000: 10). It is also the opinion of Sharma that only Harappan style ceramics, semiprecious beads and terracottas continued and that the proto-Dravidian language is attributed to them, as are the beliefs that the later peoples may have adopted into their religious practices including tree worship (Sharma 2000: 10).

This continuity is also a political issue; the modern political controversy surrounding the Harappans mainly stems from Indian nationalism, particularly with the recent term of office of nationalist Bharatiya Janata Party (BJP), which translates as "Indian Peoples Party", from 1999 to 2004. Heehs believes that the Harappan Civilisation has become an important battle in a modern Indian culture war because, while it is certain that the Harappans devised one of the most extensive societies in the Old Word, if the Vedas, that is, the Hindu scriptures, were composed after the decline of Harappans then the claims made by the nationalists that the Vedas are the primordial sources of Indian civilisation fails (Heehs 2003: 195).

Whatever the case, and there is some doubt as to whether any certainty will be forthcoming in the near future, this decline can be seen around 1900 BC. Structures became poorly built with heavy re-use of material, indicating presumably a shortage of natural resources such as clay for bricks and timber for building frames. Pottery styles start to diverge greatly and within a few hundred years the culture virtually disappeared or may be relocated.

2.4.4 Post Harappan

The aforesaid drop in trade resulting in economic stress as well as environmental stress are "push factors" (Anthony 1990: 900) that can be said to have reduced the local Harappan population and the most likely outcome of this decline was a gradual geographical migration south-east towards the more fertile Gangetic plain, which later evolves into the culture of the historic period of India.

One should remember, however, that perhaps the civilisation did not end so abruptly and possibly did influence the development of early Hinduism (Kenoyer 2005: 21, Parpola, Simo et al 1977: 164). For instance, there seems to be a clear delineation in the location of areas set aside for specific crafts in the Harappan cities. This seems reminiscent, though by no means conclusive, of the caste system (Scarre and Fagan 2003: 159) of the later historic period. Regarding caste, although various archaeologists have put forward wildly differing theories describing the probable political organisation of Harappan culture- everything from theocracy with a ruling class of priests to a republic (Jha 1991: 20 to 21), it is important to emphasise that other to attesting to a difference in the economic circumstances within a set class such as artisans, or the possible existence of a ruling elite, it is foolhardy in the extreme to make any inferences regarding the development of the caste system in the later Vedic age (Jha 1991: 21).

In addition, this is a convenient place to make one final comment regarding the "yogic" figures discussed earlier. It should be mentioned that several researchers have drawn attention to the similarity between numerous religions and corresponding religious artefacts such as these, so-called, "Shiva" figures from the Harappan regions that are thought by these researchers as later becoming parts of the Hindu religion as it developed around a thousand years later in the Gangetic plains. However, "there appears to have been little transmission eastward of the material fabric of urban life" (Kirk 1975: 21). For example, the Harappans style of architecture seems to have disappeared.

2.5 Distinctive Features of the Harappan Civilisation

The uniqueness of the Harappan culture can be seen in many aspects. This distinctiveness assists in both in the differentiation of other indigenous cultures both temporally and spatially as well as an aid for defining trade sources, routes, and destinations through an analysis of the material remains of this culture; both in the domesticate archaeology and and the archaeology of other cultures.

2.5.1 Town Planning

Subsequent larger scale excavations at Mohenjo daro and Harappa reveals a similarity in town planning (Wheeler 1966: 19). Cities seem to share uniformity in layout making the civilisation unique amongst the earliest societies. The layout of the towns generally comprises of a monumental citadel within a walled lower town with individual dwellings or houses.

Another unique feature of this society is its mastery of the use of water. Highly efficient covered drainage systems removed sewage from housing, reservoirs supplied fresh water, irrigation systems helped to grow crops and seated toilets lay above waste chutes which acted as a flush system (Jansen 1989: 189) thousands of years before the rise of Rome; all of which can be found at Mohenjo daro and, of course, there is the site of Lothal which incorporates either a dock or a fresh water reservoir; both demonstrating sophisticated engineering processes at work.

2.5.2 Typology of Artefacts

The shared typology of the artefacts of this civilisation including bead-work, pottery, clay and bronze statuary; both crude and fine, as well as toys, stone, copper and bronze tools mark it as a distinct culture sharing a distinct time-span. This is particularly the case for the Mature period. It can be described succinctly as a sophisticated chalcolithic and

ceramic civilisation, that is, they planned their cities, made pottery, could cast copper and bronze, yet still worked with stone tools.

The types of artefacts found are so distinct, in fact, that early excavators, used the type fossil technique borrowed from palaeontology and applied it to archaeology in order to identify other Harappan sites. This has inevitably led to some mistakes. It gave the impression of the Harappan Civilisation rising from nowhere, in isolation, and then disappearing. This is now known to be untrue from the work at Mehrgarh, Kulli Complex and the Kot Diji phase sites. However, during the late nineteen and early twentieth century when techniques for archaeological practice were being developed, it was an example of a novel application of a technique borrowed from another branch of science.

2.5.3 Standards, Measurements and Weights

The Harappan Civilisation also adopted precise standards of measurement. Evidence of this can be seen from the construction of various buildings where larger bricks are in the ratio of 4:2:1 (Ghosh 1990: 71).

There is also a standardised system of weights. A series of six ceramic cube-shaped weights of decreasing size have been found at Harappa; these weights can be considered essential for mass commerce and trade, one researcher states that "Weights were based on units of .05, 0.1, 1.2, 5, 10, 20, 50, 100, 200 and 500, with each unit weighing approximately 28 grams, similar to the English ounce or Greek uncia" (Mulchandani 1998). At Lothal there are cubic weights of agate, chert and spherical weights of schist and chert and barrel shaped weights (Rao 1979: 224). In addition to indicating the possibility of trade, the system of ratios and, in particular, weights give an insight into, perhaps, mathematics as practised by the Harappans (Petruso 1981: 51).

2.5.4 Writing, Language and Seals

A written pictographic language also exists as can be seen by the Indus scripts written on clay seals. Rectangular Harappan seals in the Indus region, round Harappan seals in Bahrain and one combination of Harappan script and Akkadian illustration cylinder seal from Afghanistan (Schoyen 2007). Regarding the Harappan seals from Bahrain, although fairly rare, two have been found in adjacent Bronze Age Burial mounds; in the B-South excavation, illustrating intercultural communication with the Harappan Civilisation, one is finely worked seal consisting of depictions of a zebu bull, the sun and two moons, while the other is a square seal with a round-bossed back depicting two sitting figures with the moon above them (Lowe 1986: 80).

All this again, is further evidence of intercultural contact and commerce (Parpola, Simo1977: 157). The scripts appeared as early as c.3300-2800 BC in the Ravi Phase at Harappa. It can be assumed with some degree of confidence that these seals were used in trade to mark ownership. Moreover, the Indus seals are not extensive, nor is there any Rosetta stone type object and it is different to any other known language. More recent work in some of the many, possibly at least one hundred and seventy-two thousand, grave mounds in Bahrain (Lowe 1986: 73) hopes to uncover such an artefact that may lead to their eventual decoding. And so this enigmatic script remains indecipherable to this day, despite the efforts of notable scholars as Asko Parpola and Iravatham Mahadevan and many others (Mahadevan 1977, Mahadevan 1997, Parpola 1986, Parpola 1994, Parpola and Joshi 1987, Parpola and Shah 1991, Possehl 1996, Parpola, Simo 1993).

Given the high level of computer technology used in this research it is interesting to note recent work by researchers at the University of Washington in the United states of America who have attempted to start the preliminary process of decoding this script by applying statistical methods from the fields of AI, information theory and computational linguistics in order to understand its grammar (Rao 2009, Callaway 2009).

The language of the writing has been variously theorised, somewhat confusingly, at various times to be proto-Indo-European, proto-Indo-Aryan or Dravidian. It is now thought to be

logo syllabic (D'Andrea, 2003: 23), that is, a mixture of symbols, some representing words, while others represent sounds and boustrophedon in style (D'Andrea, 2003: slide 34), that is, each line alternates in direction and is written with mirrored letters on the lines proceeding backwards.

As mentioned earlier, there is an intriguing cylinder seal that contains both Akkadian art and Indus pictographs found in Afghanistan. This seal is now part of the Schoyen Collection in Norway (Schoyen 2007) and shows, from left to right, a hunter with his dog. He is aiming his bow at a wild boar and just behind the boar and continuing around the seal to the back of the hunter is a set of Indus script symbols that appear to depict a large arrow shape, a man, a pair of bows facing each other and then numerous perpendicular dashes. This is surely more evidence of intercultural links between the Old World Civilisations, in this case Mesopotamia and the Harappan Civilisation.

2.5.5 Trade

Trade, in terms of networks, exports and imports within and exterior to the Harappan culture are both sophisticated and extensive and are indicative of strong intracultural and intercultural interactions. Trade, being so central to the theme of this work and to Harappan society in general is discussed in far greater detail in a separate section. In summary, however, one may state, that the Harappans exported and, presumably, imported a vast array of natural resources, partially finished and finished goods via a system of overland and maritime routes using pack animals, bullock carts, riverine boats and seagoing ships.

2.5.6 Industry

Industrial produce included ceramics, the beads discussed earlier, flint knapping and some copper and bronze smelting. Cotton textiles are also known to have been produced from scraps found at Mohenjo daro (Allchin and Allchin 1982: 191).

2.5.7 Religion/Burial

Artefact DK-1909 is the "Priest King" bust- variously described as "brutal" (Marshall Cavendish 1969: 18) or meditative. This carved limestone figurine was excavated about one-and-a-third metres below the surface in the northern part of Mohenjo daro (Guha 1967: 12). Though there is no indication that this is a religious artefact, scholars have debated on whether this is a deity, priest or important personage, whatever the case, the bust is finely carved and thought to be of significance to the maker. It is a torso bust that depicts a face with a trimmed beard, medium, neat hair tied into a rear bun and a slim band encompassing the head with a circle at the centre of the forehead. The male figure wears a toga style garment draped over his left shoulder. The toga has clover shaped patterns.

Fire-altars that could be associated with Hinduism have been found at Kalibangan (Allchin and Allchin 1982: 183). Some other researchers also ascribe traces of fire-pits to ritual use as is the case for the site of Rakhigarhi (Dhavalikar and Atre 1989).

The Great Bath at Mohenjo daro is thought to be a feature of ceremonial bathing which is an aspect of Hinduism (Lahiri and Bacus 2004: 314). In an axonometric reconstruction (Weaver 1966), the bath is set at the centre of an open courtyard.

There are also numerous horned figures; one depicts a man, shaman or priest sitting in what looks to be a yogic meditative position. Despite the presence of these, perhaps, proto-Shivaic figures in the art, one should point out that all the above connections to Hinduism are purely conjecture at this point or even completely mistaken (Srinivasan 1975: 56).

In addition, a word of caution should be added in that are, so-called yogic forms seen in many diverse cultures. One of the more famous examples is perhaps a Celtic representation of the horned god Cernunnos (Fray Bober 1951: 19, Geisler et al 1998) in a similar yogic position depicted on a panel of the Gundestrup cauldron at the National Museum of Denmark (Nationalmuseet 2009) discovered in Jutland, Denmark, 1891 (Conway 1911: 338) in a dried peat bog and is possibly of Gaulish or even Thracian origin

(Geisler et al 1998). However, similarity in form does not imply a similarity in the deeper meaning. In fact, there are many symbols in art, as well as similar technology that have arisen separately in many different cultures. Many of these similarities could be ascribed to parallel though separate cultural evolution. Take for example the parallel evolution of pyramidal structures in South America, Mesopotamia and Egypt and, in India, the similarity of megalithic tomb structures to those found in Europe (Perkins and Braidwood 1947: 429-430).

There are also burials and the presence of grave goods in a number of graves that, of course, are not part of normal contemporary Hindu tradition.

From the Pre-Harappan period numerous terracotta figurines, thought to be the earliest forms of female imagery found in the subcontinent, have been found from sites in Mehrgarh dating from c.4000 BC and Kulli dating from c.3000 BC (Elgood 2004: 331). Female figurines dating from c.3000 BC to c. 2000 BC have also been found at Harappan sites; most are wearing much jewellery, are draped in a short loin-cloth with a fan-shaped headdress, have pronounced breasts, necklaces, large beak-like noses and circular eye holes and there are also male figurines and clay images of bulls and other animals (Elgood 2004: 331). Harappan seals display sophisticated arrangements with the depictions of figures, as well as the, as yet, indecipherable script; some scholars attempt to associate the seal figures with fertility (Elgood 2004: 331), perhaps presumptuously, in the belief that Harappan seal art an ancestor of later Hindu art. The numerous bull figures both on seals and in figurines may also imply an association between the bull and fertility (Elgood 2004: 332).

2.5.8 Art

As well as the "priest king" bust, there are other skilfully carved pieces as well as seals, a few beautiful bronzes, such as this, so-called "Dancing girl" bronze from Mohenjo daro, where a naked teenage girl poses with her right hand on her hip and her left, bangle-bedecked arm, hangs down relaxed with her hand resting on her lower thigh. The dancing

girl is produced using the lost wax process that is still used by Indian metalworkers today (Scarre and Fagan 2003: 158).

There are also numerous clay figurines such as crude female figurines from Harappa and toy bullock carts.

The Harappans also display considerable skill in the previously discussed bead-work, this can be seen from a small pot found at Harappa on Mound E in 1998, dated to Period 3C of the Harappa Phase, that is, c. 2200 BC to 2000 BC. It is a short, narrow-necked, wide-bodied pot with a base as narrow as the neck. It contains fired steatite beads similar to Ravi phase faience beads. The beads themselves are made from the seed of the *Coix lacrymajobi*.

There are also the many "unicorn" seals. One such seal was excavated by Ernest Mackay at Mohenjo daro between 1927 and 1931. It is of the late Period IB, c.2000 BC and depicts a bullock type animal with some symbols across the top. An additional point to make is on the subject of the, so-called, "unicorn" seals that depict a one-horned bull or water buffalo. At least as far as the depiction of the animal is concerned, and this is corroborated by During Caspers who states that it is a "male bovine" (During Caspers 1991: 313), it is the opinion formulated during this research that this is simply the Harappans experimenting with the most effective way of leaving a clear and easily discernible impression of a bull clearly in the soft surface material of the seal clay. Much in the same way as the ancient Egyptians would purposefully misrepresent the proportions of the human body in order to more clearly represent three dimensional objects on a two dimensional plane. Also, perhaps the numerous, detailed depictions of the bull on Harappan seals denotes the either purely secular admiration of cattle as wealth or combined with religious veneration. Perhaps there is a slight corroboration with this view because, from narrative sources (Bradley 2003: 531), during the later Iron Age of the Assyrian Empire under Ashurnasirpal II, 853 BC to 859 BC, while on military campaign in the upper Tigris region, the Assyrians seized oxen and sheep from a village (Bradley 2003: 532). A stone monument, however, known as the Rassam Obelisk (British Museum 2009) shows various peoples of the empire bringing tribute consisting of textiles and bronze cauldrons, therefore, it is assumed that for people of this particular region, live-stock represented wealth (Bradley 2003: 532).

2.5.9 Politics and Warfare

From the archaeology of several sites it is known that, although there are some large houses, even the smallest dwellings are well-built with excellent latrine, bathing and water supplies. This could indicate greater social equality than other cultures of the time.

There were thought to be central administrative centres possibly at Mohenjo daro and Harappa and also at Dholavira in the Gujarat, given that these seem to be the largest sites.

There appears to have been no warfare or, more precisely, no real physical evidence of warfare has been found to date. There is a general scarcity of weapon finds. There also appears to have been little sign of violent death in skeletal remains including the so-called "murder" remains found in Mohenjo daro that awaits a more thorough forensic examination.

It is possible that geographical isolation may have helped the Harappans achieve this, but this does not explain a lack of internecine conflict. This has led some researchers to the assumption that the Harappans were a peaceful people. More work needs to be completed in this area before any firmer conclusions can be reached.

Factors that could conflict with this view are the heavily built defensive walls of the sites, though whether this is for defence against floods or more human enemies is debatable. Also there are the burnt levels at Kot Diji that may one day disprove this supposed lack of violent conflict.

To illustrate the hazards of making too many assumptions based on too little data it is useful to look at the work of another researcher who has attempted to analyse the social dynamics of the Harappan culture by a synthesis of the body of work on the subject that exists before the early 1980s (Chakraborty 1983: 2132). Quite apart from the uncertain Marxist analogies, it is conjectured that the ancient Harappan society is made up of "temple slaves", "semi-independent urban producers" and a "central authority" made up of

a theocracy using the yoke of a repressive religion to exert autocratic rule (Chakraborty 1983: 2136). Unfortunately in this, decidedly odd analysis- a dark mirror-universe of the equally bizarre notions of McIntosh (McIntosh 2002), the difficulty in deciphering Harappan societal norms becomes increasingly clear. It is not only under-funding and under-resourcing that disfavours further understanding of the Harappan culture, but also this type of subjective research and, if while perhaps not actually malicious, seems at the very least, careless in its conclusions. This type of research, that appears to massage archaeological evidence for whatever reason it sees fit seems like a harking back to the whole Aryan invasion debacle that was dropped many years ago.

Comparing the Harappans to other civilisations, Fairservis believes that the evidence presented emphasises that the Harappan Civilisation had little similarity to that of Mesopotamia and Egypt which both shared the characteristic of large scale public buildings, armies, warfare and slavery; features not apparent in the Indus Valley (Fairservis 1986:50). Thus, Fairservis states that perhaps there was a system of kin-based chiefdoms similar to the political systems found in Hawaii, the American north-west coast, south-east Asia or west Africa (Fairservis 1986:50).

Thus, it can be seen that in the relative vacuum of further evidence, many researchers have formed their own opinion regarding the polity of Harappan society. Apart from the relatively benign conjecture of Fairservis who postulates Hawaiian style tribal chiefdoms, there is also McIntosh who postulates a peaceful utopia (Macintosh 2002). Jha, another researcher comments on the wide ranging and speculative ideas abounding in Harappan archaeology stating that despite the main impression of a highly complex social and economic structure with the city holding a central, administrative role to the countryside which it dominates with clearly delineated class lines within the city itself and a privileged ruling elite enjoying unequal wealth in relation to the mass of ordinary people, there are serious differences of opinion by archaeologists regarding the composition of these rulers (Jha 1991: 20). Jha goes on to mention the various theories ranging from a single ruler chosen from an elite class to an autocratic theocracy (Jha 1991: 20) and even ideas of a republican state (Jha 1991: 21). Jha also believes that to attempt to put forward the idea of the later Vedic extremes of caste as evolving from the Harappan culture does not seem to have an adequate basis (Jha 1991: 21). Jha ends by stating that the difficult question of

who the authority was and how that authority was maintained, in the absence of tangible data in the material finds, can only be speculated (Jha 1991: 22).

2.5.10 Agriculture

Harappan agriculture was fuelled by alluvial silts along the rivers providing the basis for fertile, cultivable land that could be easily enlarged by simple methods of inundation irrigation, particularly along inlets, creeks and inner sides of river-meanders and this limited, but productive, region could support the development of Harappan Civilisation even before the introduction of additional summer crops such as sorghum (Sheratt 1980: 323). In the Indus basin during the harsh, dry winters, seasonal winter crops such as wheat and barley could only be grown in only in low-lying areas because they could take advantage of residual soil moisture from autumn floods and monsoon rains (Sheratt 1980: 323).

Rice, mustard, castor, cotton, kodom (a variety of millet) and gram have wild relatives in India, thus its domesticated counterparts are probably of wholly Indian origin (Hutchinson 1976: 129-130). Cotton, quite possibly may have a use in Harappan age trade as some woven and dyed cotton cloth has been found at Mohenjo daro; craft workshops, including dyers shops, have also been found at Mohenjo daro, so it can be assumed that finished textile products were wholly domestically produced (Allchin and Allchin 1982: 179).

Most importantly wheat and barley, but also to a lesser extent peas, chick peas and lentils grow wild in western Asia, but have been grown domestically in India from before earliest records, so it can be said that they have probably been introduced as wild species from west Asia (Hutchinson 1976: 130). Wheat and barley were grown and fertilised by alluvial silt and watered via the rather singular Harappan irrigation systems that made use of the seasonal deluges preceding the regular droughts.

Sorghum, millet and sesame, in the absence of any wild domestic varieties must be regarded as being introduced to India from Africa (Hutchinson 1976: 130). However, genetic, morphological and phytochemical evidence supports the domesticated sesame as

being of Indian origin descended from *Sesamum orietale* variation *malabaricum* and, in support of this supposition, burnt remains of sesame seeds have also been found at Harappa together with burnt peas and wheat (Bedigian and Haralan 1986: 140). Today this plant grows wild along the side of railway tracks as well as roadsides; from the north to the south of India (Bedigian and Haralan 1986: 140).

Part of the uniqueness of the Harappan culture was the role given to cattle (Fairservis 1986:43). Allahdino is amongst the most Harappan important sites excavated in Pakistan (Peregrine and Ember 2003: 275). It is one hectare in size (Peregrine and Ember 2003: 273) located approximately thirty two kilometres east of Karachi on a wide coastal plain, abundant in water, but limited in cultivatable soil, though with rain comes a considerable growth of grass allowing domestic animals to feed (Fairservis 1986: 43). The settlement consists of a small open court surrounded by medium sized houses and other buildings, during the excavation of the site a large quantity of small clay cattle figurines, fragments of small carts and approximately twenty-three thousand items that have been described as clay tokens have been found (Fairservis 1986:44) in addition to a well and drains that may be associated with an irrigation (Peregrine and Ember 2003: 272). Faunal evidence in the shape of animal bones indicate the importance of cattle (Fairservis 1986:45) which is reflected in the depictions on seals found at Mohenjo daro and Harappa (Fairservis 1986:46). Harappan seal tablets, in addition to other wild animals, also depict domestic ones such as goat, zebu short-horn bullock and "unicorn" bull (Fairservis 1986:46). It has also been postulated that the wide distribution, but short term occupation of Harappan settlements may have been a product of Harappan cattle herds (Fairservis 1986:47).

2.5.11 Hunting and Domestication

Wild ancestors of sheep, goats and cattle were already being used by man from evidence found in the caves at Aq Kupruk in the Hindu Kush- the mountains that separate Pakistan from Afghanistan, as early as 16, 000 years ago; this strongly indicates that even by Pre-Harappan times sheep, goats and cattle were already long domesticated (Allchin and Allchin 1982: 97) and evidence from the seals and animals remains at various sites also indicate that other animals were hunted.

2.6 Representative Sites of Each Period

The following is a brief summation of the major representative sites of importance within the main cultural migrations, economic flows and trade routes of the area.

2.6.1 Pre-Harappan: Mehrgarh

First evidence of agriculture can be seen at Mehrgarh, c.7000 BC to 4500 BC, an agricultural community on the Kachi alluvial plains of Baluchistan (Possehl 1999: 450).

Mehrgarh, a Neolithic farming village first excavated by a French team led by Jean-Francois Jarrige in 1974 (Chakrabarti 1999: 120-126) is located at a particularly significant position in the Bolan Pass at the top of the Kachi Plain where the Iranian Plateau meets the Indus flood plain (D'Andrea, 2003: 10). This area is an economic nexus in ancient times as many trade routes intersect here. The site is spread over about 200 hectares on the fertile banks of the Bolan river and it is situated in the Baluchistan area of modern-day Pakistan.

It can be assumed that the Neolithic village of Mehrgarh supported a small population on the alluvial plain of the Bolan river. The people of this site constructed, highly organised and regular rectangular clay and chaff mud-brick buildings and storage rooms and the layout seems planned and sophisticated (D'Andrea, 2003: 12); perhaps a fore-runner of Harappan civic-planning.

Annual flooding of the Bolan river made the river banks rich in the clay used for bricks and spread fertile silts onto the floodplain so that crops could be cultivated successfully- this site, in fact, shows the first evidence of agriculture in South Asia- both domesticated live-stock is raised and plant varieties were cultivated here (D'Andrea, 2003: slide 12). From analysis of the chaff in the bricks it is known that the inhabitants grew wheat and barley and. zooarchaeological evidence from early levels show large numbers of non-

domesticated species, this changes in later levels where domestic species are more prevalent, domestic live-stock included cows, sheep and goats (D'Andrea, 2003: slide 12).

This site is one of many in Baluchistan, though none are as elaborate as Mehrgarh, they do indicate a move towards village dwellings and well-ordered areas and clearly delineated spaces that are to precede the sophistication and order of the nearby cities of the Harappan Civilisation. Art from Mehrgarh has been compared to Harappan art, which lends credence to the idea of the gradual emergence of Harappan society from the wellspring of earlier cultures One should finally note that though Mehrgarh started as a Pre-Harappan site, it was still occupied well into the Harappan age.

The excavations of Jarrige have, to date, revealed several levels of occupation and some radio carbon work has also been completed by the French teams (Jarrige and Lechevallier 1977, 1980). To surmise, the earliest date is c.7000 BC and is characterised by unbaked ceramic figures then around 5500 BC, ceramics of polished red-ware, straw reinforced pottery and a cylinder seal appear and finally at 4500 BC, amongst other artefacts, there are painted and decorated ceramics and a bronze axe (Jarrige and Lechevallier 1977, 1980).

2.6.2 Early Period: Kulli Complex 2500 to 2000 BC, Nindowari

The Kulli culture was named after a site in Kolwa in southern Baluchistan discovered by Sir Aurel Stein in the early 1900s who found streets laid out in a regular grid pattern and rows of houses built from large stone blocks, other planned Kulli sites found elsewhere have Harappan characteristics, some with paved streets and terraced hills with stairs leading to upper levels (Mortazavi 2005: 110).

Kulli sites were settled from c.2500 to c.2000 BC, the people here began as nomads living in small camps, then later settled into agricultural villages that developed into towns (Mortazavi 2005: 110). The people engaged in agriculture with their economy probably based on irrigated crops; analysis of plant remains conclude that the crops included wheat, grapes and barley (Mortazavi 2005: 110).

Kulli pottery is cylindrical or barrel-shaped, often with depictions of bulls and generally grey or black on grey in colour, also occasionally Harappan style model carts have been found at Kulli sites and other distinctive Harappan artefacts have also been found including seals and a weight (Mortazavi 2005: 110).

Nindowari is in south Baluchistan, discovered by deCardi and later excavated by J.F. Jarrige and J.M.Casal, the site has a central mound rising approximately twenty five metres above the Porali River (Hirst 2004). As with other Kulli complex sites it features monumental structures and massive public buildings land remained a viable city into the main period of Harappan development from c.2500 BC to c.2000 BC, just before the start of demise of the Harappan age at c.1900 BC. Red-ware pottery cups with designs in dark brown pigment occur c.middle to late third millennium BC. Monumental structures are found along with artefacts including red-ware pottery, terracotta figurines and avian, turkey-like busts at c.2300 to2000 BC.

Although generally contemporary with the Harappan Civilisation, it is not clear whether it was an upland extension of Harappan style cities or a culture in its own right (Possehl 1999: 104).

Though a rugged and barren mountain landscape separates Baluchistan from the Indus River and the terrain is rugged and barren, many have thought that the Harappan Civilisation was connected to that of the Kulli, but more recent research suggests that this was not the case (Mortazavi 2005: 110). It is more probable that the two were contemporaneous, with the Kulli taking advantage of a strategic position along some of the main land routes between the Indus Valley and Harappan ports; this can be seen from the presence of Harappan goods at Kulli sites and vice versa (Mortazavi 2005: 110).

More recently work researchers have found Kulli Culture sites at such places as the Bampur Valley, Baluchistan; the area is a fertile river valley with blackened volcanic gravel on one side and rolling sand dunes on the other and also surrounded by various desert landscapes (Mortazavi 2005: 110). Sir Aurel Stein described this valley as a cluster of mat huts in 1932, and since the later 1966 deCardi excavations at Bampur no new work

has been carried out, hence, the Bampur Valley survey of 2002 was the first in the area since Stein (Mortazavi 2005: 110). During the 1960s to the 1970s, the chronology of Bampur was disputed, some favouring an early chronology starting at c. 4500 BC and ending c.3500 BC, others preferring a later chronology starting at c.3500 BC to 2000 BC (Mortazavi 2005: 110). There are also smaller Kulli settlements located in open plains near the remains of dams (Mortazavi 2005: 110).

Again, the scale, structure and grandeur of these sites seem to be a precursor for the later Harappan model. This seems to re-emphasise the point that, far from arising from nowhere, which was the original hypothesis posed by early archaeologists, the later Harappan culture is reflected here, both in terms of technological sophistication and aesthetic design.

2.6.3 Early Period: Kot Diji Late 4th to Early c.3000 BC to c.2500 BC

When Mortimer Wheeler published his book *Civilisations of the Indus Valley and Beyond* in 1966 Kot Diji is thought to be a Pre-Harappan site (Wheeler 1966: 86). Subsequent excavation has shown this site to span the Pre-Harappan to Early Harappan Period showing a transition towards "...characteristic Harappan forms..." (Allchin and Allchin 1982: 145).

Other aspects of the site are quite remarkable. The perimeter wall is particularly heavily built (Khan 1964: 52). Theories include its use as defence against violent seasonal floods or perhaps protection against attack by enemies. Interestingly, at the end of the early period there is evidence of two major fires, after this the material culture became predominantly Harappan in character. It is still not clear whether this is due to conquest or simply starting anew after a major disaster

Characteristics include thick walls of four to five metres high, possibly for flood or defence and wheel made pottery and copper artefacts have also been found (British Museum 2004: Periods at Kot Diji).

2.6.4 Mature Period: Harappa

Harappa is the second largest site of the Harappan Civilisation. It is a good site to examine, even somewhat briefly, as it has been excavated over many years since the initial excavations of Sir John Cunningham in the 1850s. A conglomeration of American universities, under the auspices of the Harappan Research Project (HARP) started excavations in 1986 and continue to the present day.

Judging by its size of around one hundred and fifty hectares in size, although smaller than Mohenjo daro, it is still a large city and it may have had a correspondingly large population. Its planned appearance is consistent with the general Harappan scheme of citadel mound, lower town and surrounding walls. The citadel has square towers and bastions and there appears to be a granary with areas for threshing.

For construction of housing, building material includes burnt bricks for drains, wells and bath rooms and large sun dried bricks of aproximately 28 x 14 x 7 centimetres for filling; mostly in the ratio mentioned earlier 4:2:1. Timber was used to build flat roofs and frames. There are various types of housing- single room tenements, houses with courtyards and up to twelve rooms, great houses with several dozen rooms and several courtyards. Most of the larger dwellings have private wells. Hearths are common in rooms. Every house has a bath room with waste water chutes leading to drainage channels. There are brick stairways that connected to the upper floors. Houses are built with a perimeter wall and adjacent houses are separated by a narrow strip of land.

Later, more extensive digging at Harappa has revealed an entire sequence that spans the whole history of the Harappan Civilisation and it is for this reason that Harappa is one of the most important sites today.

Major periods of development at Harappa began c.3300 BC and ended c.1300 BC (Kenoyer and Meadow 2001c). The main era of activity occurred between c.2600 BC and c.1900 BC; this has also been confirmed by seed density data from Harappa (Weber 2003: 178).

2.6.5 Mature Period: Mohenjo daro 2600 BC to 1900 BC

Mohenjo daro is the largest of all the cities discovered so far. It may be assumed that a fairly large population, of up to forty thousand (Modelski 1997) and occupied a large area of some two hundred and fifty hectares (Kenoyer 2009). It is built in the classic Harappan style like Harappa though it is larger. Like Harappa it has straight rows of covered drains and sophisticated use of engineering for the control of water as well as neatly arranged adjoined dwellings. Again the clearly delineated groups of regular structures for various purposes are present and it shares the same general layout.

Sir Mortimer Wheeler excavated this site extensively during the 1950s and 1960s. Based on the information he had at the time and his background in Roman archaeology in the United Kingdom, he made a number of assumptions, some of which have turned out to be correct, others not so. But many of the errors made by early Harappan archaeologists are understandable given the lack of knowledge of transitionary and early sites like Mehrgarh and Kot Diji.

Interesting features of this site include a brick structure sealed with bitumen (Kosambi 1965: 66) is 12 x 7 x 3 metres in size. Due to its swimming pool like appearance, it has become known as the "great bath". There have been various theories as to what the original purpose of the structure may have been- recreation, hygiene, ritual purification, however, its definitive function remains unknown.

Excavations begin in 1922 with Bannerjee and Marshall, then substantial work by Wheeler in the 1950s and 1960s followed by Dales in the 1980s.

2.6.6 Mature Period: Lothal 2100 BC to 1500 BC

Lothal is considered by some to be the only current example of a Harappan port city, however, given, the far greater amount of information that needs to be examined, it is

thought appropriate to further consider the arguments of Lothal as a port in a separate chapter (see 3 Lothal Mature Period: Lothal 2100 to1500 BC).

2.6.7 Dholavira

Another important Harappan site, worth mentioning is Dholavira on Khadir island in the Gujarat which is thought to have been a major urban centre of approximately fifty hectares, though there is no current evidence that this is a port city, it may have served as an administrative centre for the Gujarat region (Archaeological Survey of India 2009).

2.7 Summary

In summation of this chapter, it can be said that the rise of the Harappan culture or civilisation was a gradual development from pastoral nomadism to farming villages in Baluchistan, spreading to the Indus plains and ending in the refinement of Harappan cities. Uniquely among Old World Civilisations towns were planned to a similar formula that included a surrounding wall, a citadel, granaries, housing and sophisticated water control systems. This, perhaps, only varied in terms of specialised functions, for example, ports or administration centres. Agriculture was organised with granaries for storage, animals were domesticated as represented on seals and the use of irrigation systems was widespread. There is a shared typology in artefact finds such as elaborate bead-work, pottery, statuary (both crude and sophisticated), toys, stone, copper and bronze tools and a common seal script written language. Most evidence suggests that there was no sudden fall, rather a combination of environmental factors is thought to be the most likely reason for decline, though some scholars such as Possehl disagree (Possehl 2002 : 243). It is the a general consensus of opinion among most scholars that the legacy of the Harappans may have influenced the development of early Hindu culture.

2.8 Conclusion

From this chapter, it is apparent that there is the overwhelming evidence that long distance trade existed as can be seen from the presence of non-local material, the Akkadian/Harappan intercultural seal (Schoyen 2007) and other seals and various mechanisms suited to long distance trade inferred from the infrastructure of large, well organised cities near navigable rivers, evidence of large scale manufacture as well as boats, bullock carts, other pack animals and a system of weights and measures.

Thus, all the facts pertinent to a broad background understanding of the Harappans have now been presented..

As mentioned in the previous section concerning Lothal, a more detailed examination into this most unique of Harappan cities, and a purported port, now follows.

3 Lothal Mature Period: Lothal 2100 to1500 BC

3.1 Introduction

No research concerning Harappan international maritime trade is complete without an investigation into, perhaps, this most controversial and debated city due to its early description as an important port city of the Harappan culture. For this reason some effort has been made to explore this hypothesis objectively because if the balance of evidence supports Lothal as a port; this could prove a useful short-cut in identifying port city structural criteria in terms of form and function. If this proves not to be the case then the predictive model must rely on other means.

Therefore, what follows is a critical analysis of Lothal from opposing views. To commence, an in-depth study of Lothal will be conducted, based on the work of the archaeologist S. R. Rao who excavated the site, as well as a discussion of its role as a trading node and a port city as posited by Rao. Then an account of the counter-arguments, as presented by L. S. Leshnik and others, will be given. Finally, a modified interpretation of Lothal and Harappan Civilisation port sites will be proposed in an effort to balance these opposing views and formulate criteria of what constitutes a Harappan port city in the Gujarat.

It should be noted that the rather limited material, in terms of a range of good, primary references for the excavations at Lothal is due to the fact that the work there was solely the domain of the Archaeological Survey of India, under the local direction of S. R. Rao. The main sources drawn upon here are, therefore, *Lothal and the Indus Civilisation* (Rao 1973) and the rather more voluminous *Lothal: A Harappan Port Town* (Rao 1979). Also, there is some repetition here with other more generic chapters about Harappan culture where use has also been of data sources that originate in the work of Rao at Lothal.

Lothal has been thought to be the only existing and, therefore, unique example of a port city of the Harappan Civilisation (Rao 1979: 23). It is thought to be a port mainly due to the identification of a dock area (Rao 1979: 22). Due to this rather singular feature, the site

can be seen to differ somewhat from the classic Harappan layout in terms of this theorised function. Since excavation, however, alternative theories concerning the form and function of the site have been proposed and the view that Lothal was important port city of the Harappan Civilisation extension into the Gujarat is now somewhat controversial, if not wholly dismissed.

In brief; the site lies within access to the Arabian Sea via the Gulf of Khambat, also known as the Gulf of Cambay. The town is located near a tributary east of the Sabarmati river (Rao 1979: 18 to 19, Possehl 2002: Fig. 3.20). From 2100 BC to 1900 BC Rao believes that Lothal functioned as a trading station and dock (Rao 1973, Rao 1979). A rectangle basin with a spillway and a locking device to control the inflow of tidal waves and permit automatic de-silting of the channels, in form, appear to be a dock and there are also nearby raised platforms with ventilating channels that are probably granaries or warehouses (Rao 1973, Rao 1979). The site was also a centre of carnelian bead manufacture, in addition, there is evidence of specialist workshops for copper (British Museum 2004: Periods at Lothal). In fact, the tradition of stone bead-making in the region has survived even to the present day (Kenoyer et al 1991, Roux et al 1995).

3.2 Rao's View of Lothal

3.2.1 Exploration and Discovery

Shortly after the partitioning of India and Pakistan in 1947 and the problems that this caused to Harappan archaeology given that at this time most of the Harappan culture sites were thought to be on the Pakistan side of the border, the Archaeological Survey of India made a decision to explore the areas east of the Indus Valley in an attempt at locating more Harappan age sites (Rao 1979:12). A village-to-village survey of Saurashtra, also known as Kathiawar, resulted in the discovery of more than forty Harappan sites including Lothal itself, discovered in 1954 by Rao (Rao 1979:12).

Its discovery was, in part, due to Rao's assumption that the recently found site of Rangpur, with its presence of characteristic post-urban Harappan Lustrous Red-Ware ceramics, but lack of Indus seals, implied that there may have beeen potentially richer and more clearly defined Harappan sites nearby (Rao 1979:14-15). Thus, a further survey of the estuary of the Sabarmati river between Rangpur and Dholka, a non-Harappan site, followed (Rao 1979:14-15). A low-lying mound was finally discovered and analysis of surface pottery and other objects revealed Lothal to be a Harappan settlement (Rao 1979:14-15). This discovery increased the probability, that there may have been other Harappan sites in the nearby vicinity and this indeed proved to be the case; between 1954 and 1959 a total of eighty-eight sites were discovered in the Gujarat (Rao 1979:14-15). However, of these, only six can be identified as Harappan; these are Desalpur and Navinal in Kutch, Lothal, Koth and Rangpur in Saurashtra and Bhagatrav in the south (Rao 1979:14-15).

3.2.2 Physical Features, Sequences and Chronology

Lothal is located approximately eighty kilometres from the modern city or Ahmadabad, near the mouth of the Gulf of Khambat (Cambay), between the Bhogawo and Sabarmati (Salarmati) rivers, three and a half metres above a relatively flat surrounding flood plain and is frequently subject to flooding and although at present Lothal is land-locked, during the Harappan period it is thought by Rao to have been located much nearer to the aforementioned rivers and only five kilometres from the sea (Rao 1973: 50). The site lies within access of the Arabian Sea, a factor that is obviously important for maritime trade. In fact, later Medieval ports further to the south are located along the route from Lothal to the Gulf of Khambat (Rao : 1973: 51: Fig10). In terms of physical geography, Lothal is situated in the Saurashtra area; originally a group of volcanic islands separated from the mainland, between the Little Rann of Kutch; the word "rann" being the local name for salt-waste (Rao 1979: 18) and the Gulf of Cambay (Rao 1979: 1). The land is a regular, flat alluvial plain, occasionally interrupted by low-lying hills and small rivers (Rao 1979: 3). Inland, there is a wide variety of ecosystems; from desert environments to wooded green areas as well as an abundance of wildlife (Rao 1979: 3). The Gulf of Cambay is the channel connecting Lothal to the greater Arabian Sea and, although the average height of the plain is now twelve to fifteen metres above sea level, it was much lower in the past

(Rao 1979: 5-6). The area is also prone to flooding during the monsoon season (Rao 1979: 9). Plant remains at Lothal suggest a past that included large deciduous trees such as *Accacia* and *Tamarix* as well as shrubs and grasses (Rao 1979: 20). Tall grass in the Harappan age swamp-lands sustained rhinoceros and the more heavily wooded hills were able to support elephants and other fauna while rainfall is thought to have been slightly higher than the average eighty-five centimetres of today (Rao 1973: 50). During the early Holocene, the habitat of the Asian elephant, *Elephas maximus,* ranged from China to Syria and documentary, material and excavated biological sources indicate that it survived into c.800 BC as far as Syria (Becker and Hünemörder 2009). Harappan seal impressions provide early evidence of their use as working animals (Becker 2009). There are the skeletal remains of an elephant at Lothal as well as textile impressions on clay and plant motifs used to decorate pottery which suggest that cotton was present (Rao 1979: 20).

The settlement began as a small village and evolved into a port city (Rao 1979: 24). Rao believes that the site was destroyed at least four times and subsequently re-built, thus he alludes to at least four phases of development (Rao 1979: 39). Rao also believes that the Harappans migrated to this area and took control, though it is not clear as to whether this was by trade, conquest or gradual migration that led to a cultural and technological revolution (Rao 1973: 52). This theory is not supported by substantial archaeological or historical evidence, however, and seems to hark back, if somewhat mildly, to the now discredited Aryan invasion hypothesis. Nevertheless, it is probably an irrelevant side issue, as there is no reason why the original village might not have later evolved into a city based society, this is, after-all, not an uncommon mode of civic evolution in archaeology. In fact, despite the remains of artistically differing early Micaceous Red Ware, as Rao himself states, Lothal can be regarded as "essentially a single-culture site" (Rao : 1973: 54). Even artistic changes in the pottery cannot be a useful indicator of a merging of a separate, alien culture because although Rao insists on the idea of the more advanced Harappans moving into the area, he also states that "a purely Micaceous Red Ware level unassociated with Harappan products has not been reached yet" (Rao 1973: 54). Later, flooding destroyed this first village and a new wall was built consisting of both mud and burnt bricks and the typical Harappan town plan emerged with covered drains, central administration area and upper and lower towns as well as all the other characteristics of the more sophisticated culture (Rao 1973: 54). More flooding and reconstruction is indicative of later phases

(Rao 1973: 54). In short, the sectional plan from Rao's excavations of the main part of the mound reveals the relative dating of cultural artefacts. From the lowest level, just above the soil, there is a mix of both Harappan and indigenous ceramics as well as some cubic weights, then above this layer; coarse grey ware, proceeding upwards to anchor stones, copper and bronze implements, then beads, continuing to Indus seals, then a Persian Gulf seal, Mature Harappan ceramics and an intriguing Sumerian style figure (Rao 1979: 477 and Plate CCLXXV), which presumably suggests the possibility that trade was not all in a westerly direction. As mentioned before, prior to these fairly well delineated Harappan phases, Lothal was already occupied; there was a small chalcolithic village with a people who produced a distinctive ceramic ware (Rao : 1973: 54).

In addition to the relative dates available from the excavation of the Lothal mound, absolute dates have also been obtained by radio carbon 14 dating of various material. Charcoal samples from a layer sealing a mud-brick wall and a layer sealing a mud-brick house dates from 1995 to 2010 BC +/- 115 years. Another charcoal sample from a cess pool was dated 1895 BC +/- 115 years. A sample from a post-hole was dated at 1865 BC +/- 110 years and a later sample was dated 1800 BC +/- 140 years. The latest dates for the mature Harappan culture obtained through radio carbon dating of samples are from 1895 BC +/- 115 years and 1555 +/- 135 years which, in effect, pushes the dates for Harappan chronology further back than has been thought during previous excavations (Rao 1979: 39). The development of the site, designated Period A, began around 2450 BC and lasted until 1900 BC, when the decline began. This decline has been designated Period B and ended at approximately 1600 BC. These Periods have been divided into Phases of building activity. Phases I-IV take place during Period A and Phase V in Period B. Phases A and B are identified through excavations, thus a sequence of cultural periods and phases have been identified. Period A encompasses the Mature Harappan period and Period B the Late Harappan Period. Period A consists of four phases and six sub-phases and Period B consists of one phase, with three sub-phases (Rao 1979: 24). Period A begins with the indigenous cultural features more dominant than those of the Harappan, this can be seen in material culture such as the Micaceous Red Ware, which is described thus due to its colour and surface characteristics. The decoration shows continuation into the Harappan era (Rao 1979: 24-25). A summary of the main phases follows.

<u>Period A, Phase I</u>, radio carbon dates c.2080 BC +/- 135 years to c.1555 BC +/- 115 years (Rao 1979: 39) marks the Pre-Harappan conception of the settlement (Rao 1979: 23-24) and its subsequent transition to early or a proto-Harappan culture (Rao 1979: 28). Lothal began as a small village east of the Sabarmati river, the main occupations of its inhabitants was, raising cattle, fishing, growing rice and cotton, making textiles and Micaceous Red Ware pottery and bead-making. (Rao 1973: 54). The fact that the Harappans grew rice encourages Rao to assume the use of irrigation systems (Rao 1973: 50). Also, with an ecosystem favourable to large game, it is a relatively safe inference that hunting also played a role in providing sustenance for the inhabitants.

<u>Period A, Phase II</u>, radio carbon dates c.1555 BC +/- 135 years to c.2010 BC +/- 115 years (Rao 1979: 39) was the beginning of the Mature Harappan period. Rao also theorises that during the early history of the village a flood occurred and this forced the occupants to organise and re-build the settlement as planned town more able to withstand the possibility of future flooding. The new main town was built on a raised mound. A dock and warehouse, which is, incidentally, larger than the granaries at Mohenjo daro and Harappa, were also built to cope with, perhaps, increased trade. An administrative centre was constructed as well as a residential area, a separate industrial area and a cemetery were also allocated. In the typical Harappan style, there were neatly interconnecting streets and a municipal drainage system. A large, thick surrounding wall encompassing the whole settlement was also built probably as a defence against flood. The eastern part of this wall became a wharf for the adjacent dock just outside the town. Despite these improvements floods did re-occur and there was subsequent re-building work required for the administrative centre, or what Rao has called the "Acropolis", and the lower town (Rao 1973: 56). Around this time typical Harappan designs began to appear in the pottery (Rao 1979: 30) and the customary Harappan chalcolithic, that is; copper-stone, technology came to the fore and Lothal started to become an important Harappan industrial centre. For example, cotton, shell, ivory and bead manufacture became important as trade with external settlements and, further abroad, far off civilisations increased (Rao 1973: 55).

<u>Period A, Phase III</u>, radio carbon dates c.2010 BC +/- 115 years to c.1895 BC +/- 115 (Rao 1979: 39). Increasing prosperity led to an increase in population, thus the city expanded with houses and workshops. Mesopotamian artefacts began to show in the archaeology

which led Rao to conclude that there were now better international trading links. An example of this can be seen in some jewellery that was found, at what is possibly the dwelling place of a local merchant which shares similar characteristics to jewellery discovered in the Royal Cemetery at Ur. The dwelling also contains more evidence of trade in the form of four Indus seals. Rao deduced from this that products such as beads, inlaid shell and ivory were exported as far as the Indus Valley, Bahrain, the Euphrates-Tigris valley, northern Syria and Cyprus. Imports included raw material such a semi-precious stones for manufacture into beads as well as copper, tin, gold and wool. The artistry and craftsmanship of local artisans reached its peak during this period. Rao believes that the religious culture of the inhabitants also evolved to fire worship, as can be seen by the construction of public fire altars, whereas before these were limited to the interior of dwellings in the lower town (Rao 1973: 57).

<u>Period A, Phase IV</u>, radio carbon dates c.1895 BC +/- 115 years to c.1865 BC +/- 110 years (Rao 1979: 39). There was a small flood followed by a catastrophic inundation in 2000 BC. The city was destroyed by this flood and most structures, if not completely destroyed, were badly damaged. The river silted up and became blocked diverting its course by about two kilometres, thus leaving the city, rather untenable to function as a port. Reconstruction did begin again, though not with the same vigour and high-standards as during the previous phase. Much of the city was abandoned, though the dock is repaired and a new canal dug to the now diverted river. The capacity for servicing large ships, however, no longer existed and trade vastly decreased (Rao 1973: 58). By this time, it appeared that any remaining central administration and planning was now, if not completely defunct, at least ineffective. This can be seen in the poor quality of reconstruction. Further floods made matters worse and the environmental impact of constant flooding caused an increase in soil salinity that made agriculture less sustainable. The period ended with a final destructive flood in 1900 BC when the entire site was finally destroyed (Rao 1973: 59).

<u>Period B, Phase V</u>, radio carbon dates c.1865 BC +/- 110 years to c.1800 BC +/- 140 years (Rao 1979: 39) This period was marred by the final flood. When it receded a few inhabitants returned to Lothal. However, the population was not large enough to organise any useful rebuilding effort. The new dwellings that were constructed were crude and ramshackle (Rao: 1973: 60). Contact with the outside world, that is, foreign trade was

much reduced, perhaps as can be seen by the decrease in the sophistication of products manufactured; ceramic decoration became less elaborate with less pigmentation used and bangles were now made of shell rather than terracotta. Rao also believes that social and religious practices changed and there were slight signs of early Hindu culture emerging as can be seen from the copper double spiral rings of a form that appears in Hindu scripture. Therefore, as has oft been cited during this research, the Harappan culture falls into a gradual decline that was to mark its end (Rao 1973: 61).

The physical location of Lothal in close proximity to a river and close to the Gulf of Cambay was ideal for trade with external cultures. Whatever the case is, it is probable that the town evolved from its humble roots as a cattle, fishing and agricultural village with some crafts such as bead and ivory work as well a cotton textiles, to a veritable summit of development as a thriving centre for trade as a port city with merchants visiting from as far away as Mesopotamia and, perhaps, even Egypt (Rao 1973: 52).

3.2.3 Construction: Materials, Instruments and Architecture

Structures at the site were constructed mainly from sun dried mud bricks. In the early period, of Harappan occupation, they were made from a tougher alluvial clay, than was used in later periods. Kiln-fired bricks were used, but only where the construction materials needed to be water-proof, such as in drains, baths and docks.(Rao 1979: 71 and 75). Stone was not used due to its unavailability in the nearby landscape, therefore baked clay in the form of terracotta took its place for such items as weights and also floor material. The nearest stone was approximately eighty kilometres away, therefore, it was used sparingly for such purposes as tool-making, door sockets and blocks of stone for ritual utilisation, but not for general construction (Rao 1979: 72). Wood was used also, with local woods , such as *Accacia* and *Tamarix* for doors, beams and rafters, though timber seems to have been imported for ship-building and the crafting of furniture (Rao 1979: 72). Rao also speculates that teak, *Pterocarpus santalinus* and *Melias* came from forests outside the area (Rao 1979: 72). Mud mortar was generally used as a building adhesive, with lime mortar only used where, again, impermeability to water was required, for example, drains, baths and water-chutes, though some baked bricked floors of

important buildings were lime-plastered (Rao 1979: 73). The dock, which shall be examined later, had walls of mud and, therefore, lime was used to line it (Rao 1979: 73). Analysis of the mortar shows that a calcereous clay containing sand and silt, mixed with chaff was used to plaster walls, however, gypsum mortar was not used at Lothal, though it has been used at other Harappan sites, such as Mohenjo daro (Rao 1979: 73).

Evidence of various architectural instruments have been found at Lothal. There is a plumber's bob, a compass for producing angles and a ruler (Rao 1979: 73). Rao believes that these instruments were vital in order to correctly align streets, houses and drains in such a regular fashion (Rao 1979: 73).

The distinctive orderliness of Harappan sites is shown through a strong sense that Lothal was a well-planned town during Phase II. If this planning was present at an earlier stage, the evidence has been lost from the archaeological record due to the earlier flooding damage (Rao 1979: 85). The town spans an approximate rectangle of about five-hundred and fifty metres from north to south and three-hundred and sixty-five metres from east to west (Rao 1979: 85) and there is a large, thick surrounding wall (Allchin and Allchin 1982: 174, Fig. 7.4). From an examination of site plans (Rao 1979: Pl. IV) a brief description of the layout can be made. The dock is on the eastern side of the town and abuts a platform that adjoins the site boundary. Just west of the southern part of the dock are warehouse areas. West of the northern part of the dock is the lower town with its dwelling areas. At the extreme west, abutting the site boundary are the workshop areas containing kilns and a bead factory. At the centre of the site is what is described as the "acropolis", what is presumably the administrative centre for the town and south of this is the town entrance. North-west of the acropolis and just outside the town boundary there is a cemetery. The river runs parallel to the western site boundary and a tributary splits off from the main river at the north-west corner of the site boundary channelling across the northern boundary and entering the dock at its most northern point (Rao 1979: Pl. IV and Possehl 2002: Fig. 3.20). The dock is approximately 213 x 30 metre basin (Rao 1979: 123) connected by a series of artificial channels is what sets it apart from other Harappan sites. There is also a brick structure three hundred and four metres from the southern surrounding wall and a scatter of bricks and pottery approximately four-hundred and fifty-seven metres south-east of the dock (Rao 1979: 85).

Heavy pierced stones of a type still used as anchors by local fishermen have also been found just outside the dock area which adds credence to the dock theory (Allchin and Allchin 1982: 173), whether these same stones actually date from the Harappan period is another matter. On the subject of anchor stones, Rao has stated that the anchor stones have been found in an ancient river bed by the Nal Sarovar (Rao 1973: 50), a lake which is today a part of a bird sanctuary. The area in which these anchors have been found are today too heavily silted for navigation, but, presumably, this may not have always been the case.

Although there is an on-going debate as to whether the basin-like structure at Lothal is a dock or a fresh water reservoir, there is some slight archaeological evidence that the Gulf of Cambay (Khambat) situated nearby has had some importance as a maritime trade centre. The idea of Lothal as a port does not entirely rely on the "dockyard" theory, but also because it is near a natural harbour. Also, five clay boat models have also been found in this area (McGrail 2001: 251) which tends to lend, at least some credence to this idea.

The architectural arrangement of municipal zones seems to imply that trade was important, if not central to Lothal, particularly given the presence of an on-site bead manufactory.

3.2.4 Death, Religion and Politics

A probe of the western edge of the mound in 1958 revealed a cemetery area; the second grave uncovered was of utmost importance as it showed the presence of two skeletons, this was unique, in that, for the first time, it showed a burial practice of a type unknown before (Rao 1979: 137). By 1960 an additional twelve graves were uncovered and eventually a total of nineteen skeletons were unearthed; the graves spanned both cultural Periods A and B (Rao 1979: 138). The graves measure about two to two-and-a-half metres by fifteeen to thirty centimetres, though sometimes they are wider to accommodate grave goods (Rao 1979: 140). Orientation of the body is generally head to the north and lower body to the south (Rao 1979: 140). Three graves appear to be joint burials (Rao 1979: 138). The joint burials, while not unique are very rare in the Harappan culture (Rao 1979: 141). Grave

goods are present, though sparse and tend to be either personal jewellery (Rao 1979: 141) or pottery (Rao 1979: 140). The pottery is mainly earthen ware. Two graves contain animal remains (Rao 1979: 143). Finally, there is some speculation as to whether the cemetery reflects the true population dynamic of Lothal since most of the bodies are of males aged between about twenty to thirty years (Rao 1979: 145). Several bodies show signs of fracture marks on the legs and skulls and there is the body of a child which shows possible pre-mortem trephination of the skull (Rao 1979: 145). The age of the burials range from 2200 BC to 1600 BC (Rao 1979: 146). Analysis of the skulls have produced evidence of individuals of mixed ethnicities; Caucasoid, Mediterranean, Armenoid and possibly Australoid (Rao 1979: 146). This seems further evidence of intercultural exchange.

Rao believes that there was "no single faith uniformly followed" (Rao 1979: 214). In addition idols or, perhaps, votive deities differed regionally in the Harappan culture; Rao states that mother-goddess worship that was prevalent in the Indus Valley is not present in the Gujarat (Rao 1979: 214). The horned, yogic figure mentioned with caution earlier is thought by Rao to be a proto-Shiva, as the lord of beasts (Rao 1979: 215). However, this seems to be a case of Rao, again trying to tie Harappan culture to later Hindu culture. It is interesting that Rao, however, does not always portray the Harappan culture as a strong antecedent to Hinduism. This can be seen in his criticism of suggestions of phallus worship and the female counterpart to this in the form of yoni worship. Though whether this is because yoni worship interferes with his theory that the yonis are, in fact, anchor stones and that Lothal is ultimately a harbour city with boats at dock is questionable (Rao 1979: 215). Rao also compares the worship of trees, bulls and serpents with Aryan and non-Aryan practices. He mentions possible veneration of the pipal tree, the bull as a vehicle for Shiva and serpent worship in older Vedic times. However, he does note that although there is the presence of the bull as a motif on the Indus seals, these seals were used for commercial and not religious purposes (Rao 1979: 215-216). Rao also postulates the possibility of fire-worship from the mud-brick "altars" in private houses (Rao 1979: 216-217). Discovery of a terracotta ladle with smoke marks is ascribed by Rao as evidence that this is "obviously" evidence of "ritualistic worship of fire" (Rao 1979: 217). Rao goes on to conclude his view on Harappan religion by also clearly linking funerary practices

(Rao 1979: 218), knowledge of rice and the horse (Rao 1979: 219) and yoga (Rao 1979: 220) to the Aryans and Hinduism.

Rao, in general, postulates a peaceful society made up of various ethnic groups, gradually influencing and eventually displacing the indigenes of Saurashtra. Though, he admits to the difficulty of deciding who the indigenous people, represented by Micaceous Red Ware, were. Multi-ethnicity and non-homogeneous religious practices were, therefore, a feature of the cosmopolitanism of Lothal. He believes that the leader or ruler of the town was secular, rather than religious due to the lack of any monumental religious structure within the administrative centre or "Acropolis". Secularism of the elite power-base is further demonstrated from the location of the possible "fire-altars" being confined to the residential areas of the lower town (Rao 1979: 227).

Rao also speculates that the leader derived authority from wealth as well as leadership qualities and then strays, unfortunately, into a highly subjective interpretation of the seal scripts stating that the ruler was known as "friend, protector and saviour". The unnamed leader is said to have provided for civic amenities such as drainage and streets, both in the central acropolis and the lower town. He does, however, contend that the impressive view of the surrounding area available from the acropolis does not necessarily indicate military might of the ruler and his army, but instead were visible expressions of wealth, political authority and a "commanding view of the dock". His justification for a lack of military power at Lothal is the scarcity and poor quality of weapons which is a feature common to other Harappan cities (Rao 1979: 227).

Rao also believes that town-planning was "strictly enforced" (Rao 1979: 227) during the early phases, but adherence to these strict standards faded in later phases after various deluges damaged the town and he postulates the general malaise of society and lack of political will in those later, more depressed, times (Rao 1979: 228). Religion, in those trying times became more important, according to Rao, and this can be seen from the "fire-altar" built within the acropolis after it was abandoned by the ruling body or leader of Lothal and occupied by artisans (Rao 1979: 228).

He later comments, however, on the lack of clear class divide in that even the most humble dwellings, have certain minimum amenities including a bath, drain and living rooms and there is no evidence of slave labour (Rao 1979: 228). One may also speculate that perhaps the Harappan workers involved in the construction of public amenities may have experienced the same prestige that Egyptian workers are said to have experienced while constructing the pyramids of Khufu in Egypt as can be seen from the famous inscription of "Khufu's boat-men".

Thus, it appears that at Lothal, the accumulation of wealth was through trade. This is indicated by seals and jewellery of gold and silver found in some of the larger residencies (Rao 1979: 228). This importance of trade may also be seen from the artisan class of citizen as can be seen from the presence of the bead factories mentioned earlier and also the bronze smithies.

The script, as mentioned before, has been deemed to be pictographic, however, there appear to be only fifty two basic signs (Rao 1979: 170), though other scholars dispute this (Possehl 2002: 132). During Rao's work in the Gujarat, he has found signs that are in common use at Lothal, Rangpur and Rojdi (Rao 1979: 171). He later made an attempt to relate them to the, possibly later, Sanskrit of the Rg Veda (Rao 1979: 187) and, although largely outside of the scope of this research, it is also interesting to the comparison of Smith and Gadd of commonality between Mesopotamian and Indus scripts and what this might imply to trade or intercultural links (Possehl 2002: Fig. 7.5).

What all the above implies for trade and intercultural contact is debatable. However, the least one could infer is that it appears that the Harappan Civilisation seems not to have been a culture based on religion, or one leader, or even one ethnic group. The commonality inherent in the Harappan culture seems to be in commercial enterprise amongst other aspects. By this, it is meant, that the very design of the Harappan material culture and architecture seems to be a paradigm for primarily commercial adventure.

3.2.5 Products for Trade

Bead-making, ivory and shell-working,, lapidaries, bronze smithing were important (Rao 1979: 221). Raw materials such as agate an onyx were imported from places such as Ratanpura, near Rajpipla in the Narmada valley where the Harappan ports of Bhagatrav and Mehgam were also located (Rao 1979: 221). Finished items such etched and non-etched carnelian beads were exported to Mesopotamian cities of Ur, Kish, Brak, Lagash and Asmar as well as Persian cities of Giya, Sailk and Susa (Rao 1979: 221). Ivory was available locally and gold imported, probably from Mysore, steatite from Tekkalakotta, Utnur and, Maski, Chert from the Sind, wood teak from the Gujurat hills, *santalus* from Malabar and copper from Oman or Persia (Rao 1979: 221).

Rao believes that cotton, in particular, was an important export to Sumer in southern Iraq and can be seen is from an Indus seal bearing an imprint of a cloth bale from Umma, near Lagash (Rao 1979: 221), though this theory has not been confirmed by other researchers such as Ratnagar (see 4.4.1 Textiles). Lothal probably also exported inlays and gamesmen of local shell and ivory to Sumer in return for copper amulets, axially-tubed gold beads and painted earthen ware (Rao 1979: 222). Evidence of this trade includes seals, beads found in Sumer, such as an Indus seal and bone inlay at Asmar, axially tubed gold disk beads and from Ur and chert weights at Ur, Brak and Kish (Rao 1979: 222). There are also Indus type seals from Ur, Brak, Kish, Lagash, Umma, Nippur, Tepe Yahya and Susa, a cylinder seal at Mohenjo daro and circular Persian Gulf type seals from Lothal indicate exchanges in both directions (Rao 1979: 222).

3.2.6 Organisation of Trade

Large workshops at Lothal and multiple impressions on seals may indicate some type of partnership enterprise (Rao 1979: 223).

Lothal was a busy market centre servicing the region as far as Ragpur and Koth. The overseas trade means that docks, warehousing and a wharf area were required (Rao 1979:

223). Wealth and power was in the hands of a merchant class who depended on the up-keep of these trade facilities, hence they were re-built following the partial destruction at the end of Phase II (Rao 1979: 223). From a merchant's house, goods are traceable to Sumer; slipware and nine axially tubed gold pendants and, from another house, foreign pottery indicates international contact (Rao 1979: 223). Also a variety of wood and terracotta models of a gorilla and a mummy that have been found suggest trade as far as east Africa and Egypt (Rao 1979: 224). Harappan merchants established colonies at Ur, Kish, Brak, Lagash, Susa, Nippur and the Persian Gulf islands (Rao 1979: 224). Harappan ports at Balakot and Navinal serviced Lothal and Sutkajendor (Rao 1979: 224).

3.2.7 Mechanisms of Trades

Standard weights are needed for trade and these cubic weights of agate, chert and spherical weights of schist and chert and barrel shaped weights have been found at Lothal (Rao 1979: 224). Cubic weights of the type mentioned have been found at Susa, Kish and Brak (Rao 1979: 225). The cubic weights are in the ratio of 1, 2, 4, 6, 8, 16, 32, 64 and 120, the spherical weights in the ratio of 1, 2, 7, 14 and 28 (Rao 1979: 223).

Terracotta seals from Lothal bear the reverse impression of packing materials, which suggests the process of sealing was to attach a wet clay label in order to bond a seal to the package (Rao 1979: 225).

3.2.8 Transport

Land transport was by bullock cart and pack animals and terracotta bullock model or toy carts have been found at Lothal, that are the same as remain in use within the region today (Rao 1979: 225).

Flat bottomed boats were used on inland waterways, of a type again suggested by terracotta models found at Lothal and reed boats similar to these are also still in use today

(Rao 1979: 225). On the subject of larger vessels, the dock was capable of servicing large ships also similar to those in use today (Rao 1979: 226).

3.2.9 Lothal and Mesopotamia

As well as the seals, sealings, stone weights and beads mentioned earlier, Sumerian clay tablets frequently mention the import of copper from Dilmun (Bahrain) which was a meeting place for Harappan and Mesopotamian traders (Rao 1979: 232). Regarding Mesopotamian trade; as well as the steatite beads and gamesmen mentioned earlier, a copper dog and a bull amulet of Susan style have been found at Lothal (Rao 1979: 233). Also copper objects with similar shapes such as barbed fish-hooks, tanged arrow-heads, chisels, nails and rivets are found at both Susa and Lothal, perhaps indicating cultural exchange or diffusion via trade (Rao 1979: 233). A copper bird in Lothal also matches the style of an object found in a Hittite context at Alisar Huyuk (Rao 1979: 233) and a copper Harappan-type knife from a Hissar Akkadian level (Rao 1979: 234).

Pottery from Susa is slightly similar to Micaceous Red ware from Lothal and jars, vessels, beakers and vases from Mari's Larsa period and Kish also resemble Harappan pottery, but most notably at Lothal there is slipware similar to that found at Ur in the Sargonid period at Akkad (Rao 1979: 235).

3.3 Leshnik's View of Lothal

While he acknowledges that a trading link between Mesopotamia and the Harappans exists and that some contact between them occurs in the Persian Gulf (Leshnik 1968: 914), there are several points of Rao's argument that he takes issue with. The topics of contention are as follows.

3.3.1 Port Structures

On the subject of port structures in the architecture of Lothal, he proposes that this relationship between the two cultures means that account should taken of the way the harbour areas of Sumer function (Leshnik 1968: 914). He states that at Sumer the docks

were not solely places where products were transferred to and from vessels, but also market-places (Leshnik 1968: 914). Goods were exchanged quay-side at permanent mercantile establishments, taverns were also a feature of Sumerian quays, as were the residences of foreign merchants (Leshnik 1968: 914). Given this description of a Sumerian harbour, he expects to find some similarity at Lothal, but does not (Leshnik 1968: 914). He states that a Harappan port might be different in appearance to that of a Mesopotamian trading partner, but that more probably, Lothal was not the port envisioned by Rao (Leshnik 1968: 914).

There are few other basin structure known in the ancient world and the only complex structure was the harbour at Pharos of 2000 BC (Leshnik 1968: 915). The Lothal basin is much simpler, but not well designed for a dock, which is unusual given the Harappans usually sophisticated engineering skills (Leshnik 1968: 915). Vessels entered the dock from the west via an inlet channel and at the southern wall there is what is thought by Rao to be a sluice gate (Leshnik 1968: 915). Leshnik is doubtful about this arrangement as it entails ships manoeuvring at a ninety degree angle to enter the dock (Leshnik 1968: 915). Leshnik feels that this is the most significant point when considering Lothal as a port for international trade (Leshnik 1968: 915).

Leshnik also criticises Rao's changing opinion; first that the seagoing vessels actually entered the dock directly then, when it becomes apparent that the channel is too small, that flat-bottomed vessels were used to transship the goods from seagoing vessels berthed in deeper waters (Leshnik 1968: 916). Another problem is that even a small modern fishing boat weighing about one-hundred tonnes, drawing about 1.2 metres would have some difficulty using the dock, although Rao makes an uncited assumption that the basin rim was higher in the past (Leshnik 1968: 916). The issue of the spill channel is also questioned because its function is to allow the flotation of large vessels at low tide, therefore, if seagoing vessels were not moored at dock, then the spill channel becomes unnecessary (Leshnik 1968: 916). This is the case for a local modern dock at Ghogha which is a simple unenclosed quay, though Rao uses it to draw parallels with Lothal (Leshnik 1968: 916).

Another point Leshnik makes concerns the seven "anchor" stones found, five in the basin area, six of which are round with holes in the middle, one pyramid shaped, with a holes at the top, the largest being about sixteen inches, making it doubtful, in Leshnik's opinion, for its use as an anchor even though local folklore does ascribe this use to them (Leshnik 1968: 917). These objects are also found at Mohenjo daro, though his suggestion is that they may have been used at Lothal as counter-weights for a shaduf (Leshnik 1968: 917). This a see-saw arrangement for drawing water, commonly used in India as well as alongside the Nile in Egypt to this day. A bucket is attached to one end and a counter-weight at the other, making it easy for the operator to draw water without using excessive physical labour. Leshnik also draws attention to the post-holes along the embankment of the basin, thought to be mooring posts by Rao, he believes they could be sockets for the vertical arms of the shaduf (Leshnik 1968: 918).

Although two wells have been found at Lothal, Leshnik believes that the supply of water from wells may have been quite limited (Leshnik 1968: 918). Today, nearly all local settlements have a rain-water reservoir, mainly for bathing and washing and, in the hot-season, they become the only source of potable water (Leshnik 1968: 918). Most are mere ponds, although some have brick walls (Leshnik 1968: 918). There are also usually steps leading down to the water and these steps are not present at Lothal (Leshnik 1968: 918). Steps are not, however, always present as is the case at the nearby town of Dhan-dhuka, where there are no steps in the twenty acre masonry enclosed tank (Leshnik 1968: 918). The absence of an entry point to the tank at Lothal is explained by the assumed presence of the shadufs and, in any case, Leshnik believes that the main purpose of the tank was to provide water for irrigation (Leshnik 1968: 918). Thus, when necessary, water stored in the tank was lifted out via the shadufs and transported to the fields via by a system of canals (Leshnik 1968: 919). He goes on to conclude that before the canals of the Punjab and the south, irrigation was achieved mainly through the use of tanks and still are in large parts of south, and that some writers have theorised that the method originated in ancient India. (Leshnik 1968: 918-919).

He also refers to some possible evidence from Hindu scriptures. In the time of the Rg Veda, c.1500 BC, tank irrigation was known and the construction of tanks was considered

meritorious and a royal duty; this is mentioned in the Hindu epic the *Mahabharata* (Leshnik 1968: 919).

The area around Lothal is fertile, able to produce cotton, wheat, barley (Possehl 1986: 467) and other crops and has an annual rainfall of approximately seventy-six centimetres which is enough to the meet the requirements of crops, however, rainfall distribution is not predictable making agriculture difficult without a means to control the distribution of water (Leshnik 1968: 919). To alleviate this problem, in the last century, tank irrigation was utilised during the cold dry months of November and December to bring rice crops to maturity (Leshnik 1968: 919). In such cases, part of the field was used as a rainwater pond so that if the later rains fail, water could be carried out from the pond to the rice beds via a channel or water-lift (Leshnik 1968: 919). Because Lothal is a place in India where early use of rice has been proved, the facts about rice cultivation become important and the presence of the granary at Lothal implies that agriculture and, therefore, the irrigation system was also subject to administrative control (Leshnik 1968: 919).

A problem with tanks is that they retain the silt of stored water and must be regularly cleaned; the basin at Lothal was lined with bricks making the task of cleaning much simpler and allowing for a greater life of usage as well as protecting the basin from water erosion (Leshnik 1968: 919).

Leshnik surmises by stating that the identification of Lothal as a port of international commerce seems to be questionable because arguments favouring this are based on little evidence and relies on proving that the tank or basin was a dock capable of receiving seagoing vessels (Leshnik 1968: 919). He ends in stating his hypothesis of its use as an irrigation tank and, secondarily, as a source for potable water, while lacking decisive evidence, seems more probable given the rural nature of Lothal (Leshnik 1968: 919).

In his paper, he also outlines some further problems, extraneous to the dockyard.

3.3.2 Problems Regarding Exports

Regarding exports to Mesopotamia, Leshnik accepts that the export of cotton may have occurred, but not the export of grains which could be grown locally in Sumer (Leshnik 1968: 914). He also states that raw gem stones may have come from Lothal via central India, agreeing with Rao, but that the copper probably came to Sumer from Rajasthan rather than Lothal (Leshnik 1968: 914). His view is also that the number of objects identified as foreign, including the Persian Gulf-type seal, a seal impression, copper ingots and pottery sherds are too few in number for one to draw any reasonable conclusion as to their origin (Leshnik 1968: 913-914) and also that the same pottery-types have been found at other sites in the region (Leshnik 1968: 914).

3.3.3 Problems of Scale

After stating that the Harappans engaged in little overseas trade, he then takes issue with the size of Lothal, expressing the unlikelihood of regular international trade "in hands of relatively minor settlements such as Lothal" (Leshnik 1968: 914).

3.4 Other Views of Lothal

Also, one may note the views of more current Harappan scholars such as Gregory Possehl, who has worked at the Gujarat site of Rojdi, who states that-

> "Some scholars propose that the large, brick-lined enclosure on the eastern side of the settlement was a dockyard or harbour for ships involved in commerce, but this has been disputed by others, including Thor Heyerdahl. Most archaeologists feel that this enclosure was an ordinary tank for the storage of water." (Possehl 2002: 80).

He also states in review that the book by Rao, *Lothal and the Indus Valley Civilisation* is an attempt to "sell Lothal" in order to equate Lothal's importance in the Harappan context with the largest cities, whereas it is a fairly small site in comparison to Mohenjo daro and Harappa (Possehl 1975: 164). However, Possehl has also stated the importance of Lothal as a dynamic commercial and manufacturing centre (Possehl and Kennedy 1979: 592).

Whether Lothal itself was a port, even without taking into account the dockyard problem, remains a question difficult to answer. Shereen Ratnagar, a scholar who has attempted to interpret Harappan trade, has the following to say, regarding the possibility of using the nearby Gulf of Cambay for shipping, "this Gulf has extreme ebb and flood ranges…the tidal range can be used to advantage by sailors, but also poses a threat to the unwary or inexperienced" (Ratnagar 2004: 97)

On the other hand Dilip Chakrabarti of Cambridge opposes this and fully supports Rao and states that "the presence of marine organisms detected inside the enclosure has more or less proved that this was really a dockyard" (Chakrabarti 1999: 173)

3.5 Proposed View of Lothal

Although there is evidence that, perhaps, Lothal was not purpose-built with docking facilities, that does not invalidate the work of Rao completely. Also, it should not conflict with the search for riverine trade routes, or the fact that many of the Harappan cities of the Gujarat, or indeed all Harappan cities bordering on navigable water of some type, as many do, were, at some scale, port cities. This is because the riverine/maritime trade network proposed here may be based on nearby beaching and subsequent short-distance overland transshipment by pack animals or bullock carts to the cities themselves. Therefore the above arguments should not detract from the research here as it is fairly undeniable that some of the Harappan sites in the Gujarat were involved in maritime trade (Chitawala 2004: 95). In brief, therefore, an attempt shall be made to explain the mechanisms of maritime trade in the Gujarat and, hopefully, the predictive model designed in this research can be used to test these ideas.

3.6 Summary

3.6.1 According to Rao

Lothal, with buildings facilitating international trade and a location near a river and close to the Gulf of Cambay, made it the ideal centre for trade with external cultures further west. Excavations by Rao have revealed a possibly wealthy merchant class who may have been organised into a hierarchy of a wealthy merchant class and artisan guilds and the presence of an on-site bead manufactory seems to also imply that trade was important. Products for export included beads, ivory, shell, semi-precious stones, bronze and gold. The relationship of Lothal with Mesopotamia included exported copper and possession of similar everyday objects within both cultures suggesting material cultural diffusion through trade.

Mechanisms assisting trade included standard weights similar to those found in Mesopotamia and use of seals. There were also Harappan merchant colonies in foreign lands. Transport in order of size included pack animals, bullock carts, reed boats and large seagoing vessels.

3.6.2 According to Leshnik

Findings at Lothal are too few to indicate international trade and structures were more likely to have been built to assist in agriculture.

3.6.3 According to Others

The balance of opinion, namely Ratnagar and Possehl, tends to disfavour Lothal as an international port, however, Chakarabarti sides with Rao.

3.6.4 Proposed View

It is proposed that goods were transported to and from port sites via a chain of water borne vessels and transshipped by pack animals and bullock carts; this hypothesis is not affected by the arguments surrounding Lothal as a port city.

3.7 Conclusion

The tendency of Rao to ascribe anything that does not interfere with his view Lothal as a dock to evidence of proto-Hinduism is unfortunate in that it detracts from some of his more well-reasoned arguments. Also the many statements not supported by cited evidence do not assist other researchers formulating useful opinions.

The work of Leshnik though thorough, seems to contradict most of Rao's more significant observations to the point of completely re-designating Lothal to an agrarian settlement. And, although finds supporting international trade are sparse, they are not entirely absent either, in any case finds are sparse in general for the whole Harappan culture, therefore to say that no international trade takes place at Lothal may be somewhat an over-simplification on the part of Leshnik. Regarding the storage of water proposed by Leshnik and supported by others, such as Possehl; a recent article puts forward the conjecture that increased scarcity of water in the region is a modern consequence of post independence mismanagement of resources rather than a natural occurrence (Bharwada and Mahajan 2002: 4859). However, the water storage tank hypothesis, may be confirmed by the site of Dholavira where there is strong evidence of a complex reservoir system (Archaeological Survey of India 2009, Bisht et al 2000).

There is one final point of interest that can be made regarding the work of Rao at Lothal. Rao mentions that Lothal was located in an area frequented by flooding (Rao 1973: 50). Perhaps the tank has some function as a device for preventing flooding of the city. In fact, the need to avoid flood damage has already been noted with the past reconstructions at

Mohenjo daro (Raikes and Dyson 1961: 63, Dales and Raikes 1968) and the risk of water damage to the site remains, even to this day (Archaeology 2009).

Trade has been briefly touched upon here, but as the purpose of the predictive model is assist in explaining the maritime trade and exchange networks, a more in-depth study, specifically concerning trade is now required.

4 Trade and Exchange

4.1 Introduction

Trade is central to this research in that is proposed that the raison d'être of the short, but rapid rise of the Harappan culture was partially due to its success in the arena of trade. For this reason, it is important to now investigate trade in terms of mechanisms, routes and commodities.

As shall be explored later in this chapter, the most obvious reason for the success of Harappan trading was the richness of the region in terms of natural resources and highly organised manufacturing infrastructures. These are perhaps strong enough by themselves to justify intercultural trade, even if consideration is given to the relative geographical isolation of the Harappans. The Harappan Gujarat, with its strategic placement and access to both the coast and the interior as well as complex political and administrative organisation; as can be seen from highly planned cities, are all necessary factors in a successful trading city (Kuhrt 1998: 18, 23). Although this role of state has been countered before, for example, by Garnsey in the 1980s (Morris 1991: 46), it is not inconceivable that rich merchants with fortunes made through commercial adventure had the financial power to exert political control either directly or indirectly.

Also regarding the areas intercepting the Harappan extent, Gregory Possehl has described the regions ranging from Mesopotamia in the west to the Indus in the east and as far as the Caspian Sea in the north and the Persian Gulf and Arabian Sea in the south as the Middle Asian Interaction Sphere. This emphasises the richness in shared artefacts, including trade and exchange items in the area at c.3000 BC (Possehl 2002: 215).

As it has been noted earlier, the Harappan peoples traded using both land a sea routes, however, an in-depth look at maritime trade will now be taken. Before embarking on this, however, it is necessary to refer back to what has been revealed during this study concerning the very structure or planning of the Harappan cities as this could have a direct link to evidence of trade. For example, the site of Harappa with its massive walls and

gateways that could have been used control mechanisms for the purposes of taxation and to limit commercial access rather than for defence (Kenoyer 1997:263). Also archaeological work at this and other sites has focussed on themes such as segregation, organisation and control of specialised crafts and production; all are indicative of civic planning and regulation for the purposes of trade efficiency (Kenoyer 1997:264).

4.2 Trade Dynamics and Mechanisms

There are, perhaps three main processes involved in exchange, trade and commerce (Lamberg-Karlovsky 1972).

4.2.1 Direct Contact

This is where goods are simply taken from place A to place B directly without any use of intermediaries; this may also include trading colonies by one of the members at or near the settlement of another member, or trade using direct contact that is usually organised by one of the parties (Lamberg-Karlovsky 1972).

4.2.2 Exchange

Here goods are passed from places A to B and moved between the sites arbitrarily; it may be difficult to distinguish traded goods with those produced locally through diffusion of style or function (Lamberg-Karlovsky 1972).

4.2.3 Central Places and Centre-Periphery Relationships

For example, take central places, here place C is introduced, this is located away from places A and B and is of a separate culture. If place C controls the means of production or resources needed by the two other places, then it can be described as acting as a central

place. Place C may then act as an exporter or as a transhipper, that is, acting as an intermediary between places A and B. Another scenario that may be considered is that the goods, material or transshipment might be under the control of the peoples of places A and B who reside at place C for this very reason (Lamberg-Karlovsky 1972).

Various theories of trade organisation in the Harappan Civilisation incorporate a sense of central places (Lamberg-Karlovsky 1972: 222) or perhaps a centre-periphery system evolved so that large cities such as Harappa, Mohenjo daro and towns such as Lothal acted as a central market, redistribution point and, perhaps, administrative centre for the surrounding areas. Such evidence of central places can be seen at, amongst other places, the island of Bahrain in the Persian Gulf (Lamberg-Karlovsky 1972: 226).

Thus, there is much that can be learned about the organisation of Harappan trade through an examination of other, better researched areas of the Old World. Christopher Edens, in fact, is a researcher who uses the example of Persian Gulf trade as a way of explaining political, cultural and economic aspects of ancient centre-periphery systems (Edens 1992: 118). His analysis of Bronze Age trade in the Persian Gulf is based on a description of agricultural societies where state authority takes precedence over any simple logic governing the allocation of resources (Edens 1992: 118).

This kind of analysis, can assist, perhaps, in applying the same model to Harappan trade relations, at least from a chronological and perhaps a technological stand-point. However, the Persian Gulf trade and the area of Bahrain functions more as an interaction zone between the cultures of the Mesopotamians and that of the Harappans. Mesopotamia supplied a demand met by the Harappans who were, primarily, the suppliers through the intermediary region of the Persian Gulf regional nexus. Therefore, it is difficult to use Persian Gulf trade dynamics as an example of direct Harappans trade.

However, these factors do add support to the very existence of Harappan ports which have still not been satisfactorily proven to have existed. This is because ports were not merely the source or destination of goods, they were also staging areas for products and raw material that was to be transshipped to areas further afield. There is also evidence of the Harappans Civilisation being an intermediary staging post. This can be seen from the

movement of certain commodities. A good example of this would be tin. During this period Afghan tin, on its way to Mesopotamia, was routed south via the Indus by boat in preference to the overland route across the Iranian plateau (Potts, T.F. 1993: 392). This maritime route was the source of accounts of tin arriving via Meluhha (the Harappan Civilisation), Magan (Oman) and Dilmun (Bahrain) (Potts, T.F. 1993: 392). This is further evidence of the existence of real Harappan ports concerned with international trade rather than simply market places for local areas.

Edens also believes that the Mesopotamians of this time were able to use the threat of military action to "extract large amounts of wealth and labour from the peripheries" with trade being a tool of diplomacy (Edens 1992: 118). Trade was, therefore, part of an armoury that included warfare and diplomacy (Edens 1992: 118). Again while not contesting these views; how one may test these hypothesis in the Harappan sphere is problematic and limited to theory rather than factual analysis.

Edens does not believe that a Wallersteinian world system (see 4.2.6) is possible given that centre-periphery relationships at this time are not sufficiently developed (Edens 1992: 118).

4.2.4 Which Process?

The main point to consider is that these three mechanisms "are not mutually exclusive systems and that all three types maybe coexistent" (Lamberg-Karlovsky 1972: 222).

One should note that there is a criticism that theoretical research into the models for city formation are not completely effective in explaining power in society. However, it is thought that, in the case of Harappan cities, economic models are still of some use in the absence of other strong definitive data as long as they are not taken for granted (Whittaker 1995: 22).

4.2.5 Movement, Banditry or Exchange

It could also be argued that the presence of foreign artefacts does not necessarily imply trade, but merely the movement of such items from one area to another (Morley 2007:2). However, the example Morley uses of animals from North Africa shipped to Pisa for the arena via the Mediterranean does not entirely support this scenario. For example, the animals could have been trapped directly rather than exchanged or traded. This can hardly be said to apply for finished goods such as regionally distinct pottery.

One could, of course, assume the possibility of theft or acquisition through looting, raiding or warfare, however, given the lack of strong evidence for war in the Harappan culture, this possibility does not currently seem likely. Further, Morley's criticism of Cicero's lack of objectivity in describing the hypothetical moral dilemma of the thoughts of a merchant regarding fairness as opposed to amoral profit (Morley 2007:17, Cicero 44 BC: III-XII) seems a little unfair. From subjective experience, its is believed that even young school children unaware of the term "trade", will swap small items with each other with only the small minority occasionally resorting to gouging, theft or violence; though admittedly this is due more to a Rapopportian tit-for-tat strategy (Rapoport 1965) rather than any concious attempt at a Nashian a equilibrium (Nash 1950).

4.2.6 Capitalism

Immanuel Wallerstein offers some interesting thoughts on capitalism. Wallerstein believes that the main aim of capitalism for the entrepreneur is to "maximise accumulation"; an aim that may not be shared with the worker (Wallerstein 1995: 17). This simply throws up many more questions regarding the economy of the Harappans, given the presence of many workshops and obviously varying levels of wealth displayed in the size of dwellings, were the Harappans a completely entrepreneurial society? It seems rather impossible to base every aspect of a society on capitalistic competition as can be seen from the failure of the attempt to commodify every aspect of state apparatus by Thatcherite governments and the various public-private partnerships continued by New Labour in the United Kingdom over

the last thirty years. For example, with such a system it would have been impossible to administer the complex machine of a Harappan city with its sewer systems, orderliness and its maintenance, at least during the Mature Period. This, of course, does not necessarily imply an equal, socialist utopia; it could imply a repressive and/or feudal (Rissman 209-210) or fascistic state. Despite difficulties of fit, an attempt has been made by the researcher Shereen Ratnagar to consider the trading relationship of Mesopotamia with the Harappans using world systems theory; she comes to the conclusion that it is difficult to detect the dynamism inherent in such a system from current archaeological data (Ratnagar 2001: 375).

Nevertheless, suggestions of trade is strong. There is much evidence of both internal and external trade. Internal trade is probably evident from the amount of raw materials and finished items found at various sites. At Mohenjo daro, amongst other items, there are twenty-one objects fashioned from stones. At Kalibangan there are various stone tools distinctive to the hilly Sukkur-Rohri region of the Sind (Chakrabahti 2004: 31).

On the subject of external trade there two forms of evidence; Indus objects found at non-Harappan sites, for example, Mesopotamia, Afghanistan and Turkmenistan and non-Harappan objects found at Harappan sites. Most telling is the Harappan traders settlement at Shortugai in Afghanistan (Chakrabahti 2004: 31). In Mesopotamia, at sites including Kish, Nippur, Lagash there are Indus seals and beads. Seals are also found at intermediary sites such as Bahrain, Failaka and Oman (Chakrabahti 2004: 32).

4.2.7 Sling shots, Money or Trade Tokens?

Along with other controversies, there still remain many other unsolved enigmas endemic to Harappan research, the seal writing is still, of course, to be deciphered, but there are other questions that also remain.

A simple and relevant example to a discussion of trade is the quantity of inscribed clay balls that have been found at many of the sites. Early on in the planning stage of this research, during a visit to the British Museum, these were presented for inspection (British Museum 2003).

With no prior knowledge about the provenance of the pieces, it was assumed by the researcher that given, the quantity and design of these these artefacts, perhaps there could be some form of currency.

Although most other researchers are of the opinion that these are probably clay pellets from slingshots (Pruthu 2004: 128), it was the opinion formulated in this, admittedly minor study, that the objects were far too light in weight and elaborate in design to be simple missiles particularly when compared to other items described by the British Museum as slingshots (British Museum 2009: AN54742001).

A brief investigation on Jstor a few years later show that this was perhaps not such an original idea and, at an earlier date, at least one other researcher has theorised that such objects may be related to trade, though not quite in the form or currency and not in the Harappan context.

The story begins somewhat earlier in the archaeology of Susa, the Elamite capital, in Iran east of the Tigris where small regularly shaped clay objects that Leibermann calls "bullae" were discovered and thought to be possible precursors to writing in the Near East and used as a type of accounting devices (Leibermann 1980: 83).

This theory is supported by cuneiform documents excavated at Nuzi in Iraq which describe the use of such objects in earlier times at Sumer where clay calculi were used as a method of bookkeeping (Leibermann 1980: 83).

By transplanting this theory of usage to the Harappan Civilisation and, given the close trading relationship that they shared with the Near East, perhaps it is not beyond the realms of possibility that the Harappan clay balls found at Mohenjo daro and thought by Marshall to resemble slingshot (Marshall 1931: 153), may have had an important function in the trade and exchange mechanism; a function hitherto unthought of. It goes without saying, that this may be a worthwhile avenue for further research.

4.2.8 Harappan Influence on Trade in the Persian Gulf

During the first phase of the Dilmun kingdom in modern Bahrain, from c.2050 BC to c.2000 BC, there was considerable influence from the Harappan Civilisation, in terms of the beginning of official sealing procedures where a Harappan type stamp seal was chosen rather than the cylinder seal used in Mesopotamia (Eidem and Hojlund 1993: 446). Also the art of the seals shows a measure of similarity with Harappan seals and the weight system of Dilmun and the shapes of the weight stones are identical to the Harappan system (Eidem and Hojlund 1993: 446).

Harappan pottery has also been excavated from settlements and burials sites in Bahrain, with local pottery indicating some influence from the Harappans , particularly with regard to painted designs (Eidem and Hojlund 1993: 446).

Inscribed objects in Dilmun during this period were stamp seals with the Indus script, two of these seals as well as a Harappan graffito have been found at Qalacat al-Bahrain and from burials sites in Bahrain there are a further two stamp seals with Harappan inscriptions (Eidem and Hojlund 1993: 446).

The current assumption is that these seals were the property of resident Harappan traders in Dilmun, though it may be equally possible that during this period the Dilmunites adopted the Indus script (Eidem and Hojlund 1993: 446).

A fuller discussion regarding the trade goods themselves will follow shortly, after an examination of the Harappans main trading partners.

4.3 Trade Partners

Regarding the extent of trade, T.F. Potts believes that a particularly notable feature to have arisen has been the extent of trade and other forms of intercultural contact between various early cultures including that of the Harappans, the Arabian Gulf, Iran, southern Turkmenia, and Bactria (Potts, T.F. 1993: 380). As can be seen in the following sections there has been evidence of this direct, as well as, indirect intercultural contact via, perhaps, trading colonies in the Persian Gulf area. The various Harappan objects found in Bahrain indicate that Harappan and Sumerian merchants may have resided there for a period of time (During Caspers 1984: 29). Thus, the Mesopotamian place names for the locations of both the Harappan Civilisation and these Persian Gulf entrepôts, terms that are used time and time again during this research, becomes crucial to understanding change and exchange interrelations during the period of Harappan urbanism. Therefore, although, these topics have been mentioned elsewhere in this research, it is useful to now summarise evidence of these locations.

Although nothing is completely certain (Hansman 1973), there are accounts of a maritime route for Afghan tin on its way to Mesopotamia; the tin traveled south via the Harappan Civilisation (Meluhha) and then west to Mesopotamia via Magan (Oman) and Dilmun (Bahrain) (Potts, T.F. 1993: 392). Also cuneiform texts from the reign of Sargon the Great of Akkad, 2334 BC to 2279 BC, indicate that merchants from Ur engaged in foreign trade, the text goes on to describe how ships from Dilmun, Magan and Meluhha docked at Akkad (Possehl 2002: 218), other texts confirm that Dilmun is the island of Bahrain, Magan is thought to be Oman and/or south-eastern Iran and Meluhha- the Harappan Civilisation (Possehl 2002: 219, Allchin and Allchin 1982: 188). Additionally, the Dilmun culture is

"strongly represented" in the slightly later Kassite period in Mesopotamia, c.1600 to 1100 BC (Howard-Carter 1987: 115). Finally, it should be remembered that the Persian Gulf region is a cosmopolitan trade centre with a chronology that pre-dates the Harappan period and continues through the historic, medieval and colonial periods to the modern era.

4.3.1 Early Trade

Humans began to be influenced by intercultural interactions from prehistory onwards, from the earliest days of history, in fact, as soon as *Homo sapiens sapiens* emerged at approximately 200,000 to 150,000 years ago and by c.15,000 BC, mankind had populated almost all of the habitable zones of the world (Bentley 1996: 756). From the study of languages and their distribution, archaeology, families and blood type scientists have been able to follow the ancient migrations of peoples with great accuracy (Bentley 1996: 756). Widely ranging material artefacts indicate that prehistoric peoples engaged in long distance communications; by the late fifth millennium BC there were innovations in transportation technology including the domestication of horses, then by middle of the fourth millennium BC the Egyptians and Mesopotamians constructed seaworthy vessels enabling them to sail in the region of the Persian Gulf, Arabian Sea, Red Sea, and Mediterranean Sea, thus assisting in the formation of intercultural links (Bentley 1996: 756). During this time wagons and wheeled carts and appeared in Mesopotamia and the steppe region of the Ukraine and southern Russia, thus further improving transportation technology; this was the foundation of intercultural interactions during the time period between c.3500 BC and 2000 BC, heralding the first period of Old World complex civilisations with the establishment of agricultural cultures in Mesopotamia, Egypt, India, and China (Bentley 1996: 756). Further intercultural contact is evident because a substantial body of material evidence survives to demonstrate that during the third and second millennia BC trade passed between Egypt, Syria and Turkey in the west, to Afghanistan and the Indus River valley in the east, indicating that these early societies did not develop in isolation (Bentley 1996: 757). Trade was particularly important for Sumer in southern Mesopotamia because of the lack of natural resources required to maintain their society; the Sumerians traded textiles and grain in exchange for luxury goods such as lapis lazuli, which came from as far away as Afghanistan, as well as raw materials such as copper and tin, therefore, it is certain

that cultural exchanges inevitably followed (Bentley 1996: 756) these early foundations of international trade network infrastructures.

4.3.2 Local Trade and Exchange

Taking even the small site of Lothal as an example, Possehl, while still disagreeing that Lothal was a port argues the case of Lothal as a dynamic commercial and manufacturing centre (Possehl and Kennedy 1979: 592). He goes on to describe the lack of resources available locally to produce these goods (Possehl and Kennedy 1979: 592) and therefore hypothesises an exchange relationship with hunter-gatherer groups possibly at locations such as the microlithic site of Langhnaj one hundred kilometres north of Lothal (Possehl and Kennedy 1979: 593). There is material evidence for this hypotheses with the presence of Harappan style artefacts such as black and red pottery, steatite disk beads, a copper knife and a radio carbon date placing occupation at around the same time as Lothal (Possehl and Kennedy 1979: 593). There is also phenotypical evidence from an analysis of skeletal remains at the Lothal cemetery where a significant difference has been found between the Lothal Harappan population and the populations at other Harappan cities such as Mohenjo daro and Harappan, while there is a marked similarity with more local hunter-gatherer groups; further suggesting exchange between those two peoples (Possehl and Kennedy 1979: 593).

4.3.3 Contact with the Oman Peninsula

Evidence of contact of some type between the Harappans of the Indus Valley and the area of the Oman peninsula can be seen at Tell Abraq (Potts, D.T. 1993: 426). Tell Abraq is about mid-way up the western coast of the Oman Peninsula and is in the Northern Emirates of the United Arab Emirates (Potts, D.T. 1993: 424). Excavations have revealed that during the Old Akkadian period Harappan weights and pottery sherds from numerous storage jars thought to be of characteristically Harappan origin have been found within the hearth of a large, circular fortress tower (Potts, D.T. 1993: 426).

4.3.4 Trade with Mesopotamia

There is other evidence of links between the Harappans and Mesopotamia. In reviewing works on the history and archaeology of Bahrain, Potts surmises that the majority of evidence strongly supports contact between the Harappan Civilisation and Mesopotamia in the Ur III period; this contact starts, at the earliest, around the beginning of the Sumerian period and the end of the Akkadian period (Potts 1985: 687). Other evidence of the presence of Harappans, or at least Harappan exchange in Bahrain, is a copper-bronze goat figurine found at the Jefferson tumulus, Hamala North in north-west Bahrain (During Caspers 1987: 45 and Plate 1.1).

Evidence of trade between the Harappans and Mesopotamians can also be seen in the Persian Gulf where continual excavations between Failaka island and the Oman peninsula have made it possible to understand the sequence of cultures in this area and has assisted archaeologists to record the important economic role that this maritime passage is thought to played (Potts, T. F. 1993: 379). From written document sources, it is known that the Persian Gulf was a source of metals and stones and also acted as a staging post for trade between Mesopotamia and the Harappans (Potts, T.F. 1993: 379).

During the reign of Sargon the Great of Akkad, 2334 BC to 2279 BC, cuneiform texts reveal that merchants, particularly from Ur, traded with other countries. The texts describes how ships from Dilmun, Magan and Meluhha docked at Akkad (Possehl 2002: 218). The locations of Dilmun, Magan and Meluhha, described earlier, are important to a study of Harappan trade because they describe the most logical trade routes linking the Harappans to Mesopotamia.

An interesting point to consider concerning the port of Masqat, the capital of Oman, is its long association with India. Even in recent times, c. 1870s, the ruling Al Bu Said family was usurped, at least from an economic standpoint, by the wealth of Gujarati merchants (Allen 1981: 39), prior to the later discovery of oil and considerable British military assistance.

This Harappan relationship with the Akkadians as well as Oman indicates that a maritime route was the only economically feasible way to transport large amounts goods between these locations (Ratnagar 2004: 213). This chapter, therefore, will continue to focus on maritime trade, looking at commodities flowing between Mesopotamia and the Harappan regions. This will enable sea routes and points of origin and destination within the Harappan region to be located. Mackay admits the possibility of the existence of a sea route because the shoreline of Baluchistan occasionally allows for landing. He also mentions that vessels of more modern times are not that much more technologically superior-

> "At the present day a considerable amount of trading is done by vessels sailing from various western ports in India to the Persian Gulf and even direct to Aden, journeys which might well have been performed in ancient times, for the ships could hardly have been much smaller or primitive in appearance than some of those that make the voyage now" (Mackay 1935:197-198).

Although he stated this in the early 1930s, vessels have perhaps not changed so much in eighty years, apart from the greater general availability of marine engines.

Also, further support concerning maritime trade between the Harappans and Sumerians using seagoing vessels is given by Potts who states that from Akkadian times and onwards, there is sufficient evidence that maritime trade existed and that this trade can be assumed to have been conducted using boats (Potts, T.F. 1993: 389).

One brief point of caution should be made, however, on the subject of using Mesopotamian cuneiform texts as a source of information. Perhaps Mesopotamia was indeed a vastly wealthy consumer of these goods (Ratnagar 2004: 107-109) much as the United States of America is a major consumer today. However, the texts may be misleading, seemingly giving the impression that most of the trade concerns imports into Mesopotamia. This may be simply because it is only the Mesopotamian texts that are available. In the same vein, a last point that perhaps should be considered, is that since Mesopotamia was possibly the larger consumer, evidence of trade is likely to remain at the destination (Tyler 2005b). For example, Indus seals may have remained in Mesopotamia along with the goods they

arrived with. This could explain why no Mesopotamian seals have been found in the Indus Valley in a Harappan context (Lamberg-Karlovsky 1972:223).

An example of direct trade, albeit with traders from the Harappan Civilisation travelling to Mesopotamia and not vice-versa, is at Tell Asmar where Indus seals along with distinctive Harappan artefacts have been found (Chakrabarti 1975: 341). This, however, does not imply that every Harappan city directly engaged commercially with Mesopotamia (Chakrabarti 1975: 341).

Exchange mechanisms can be proposed by the "distribution of materials appearing as rare occurrences in the Harappan Civilisation, Mesopotamia and on sites between both areas" (Lamberg-Karlovsky 1972: 224). Examples of this distribution can be seen in the figurines found at Nippur, the dice at Ur and beads from Kish (Lamberg-Karlovsky 1972: 226).

Evidence of central place trade can be seen at Tepe Yahya where carved steatite bowls have been found that are identical to those found at Mohenjo daro, Kish and Tell Asmar. Another central place is probably Bahrain from where goods were most likely to have been transshipped (Lamberg-Karlovsky 1972: 227).

4.3.5 Trade Colonies

As well as the aforementioned evidence of trade within the Harappan cities and the evidence of Harappan artefacts from Oman, Iran, Iraq, Afghanistan and Central Asia, such as beads and pottery, at Shortughai there was also a Harappan trading colony indicating cultural and trading links between Harappan regions in India and Pakistan (Lawler 2008). Shortughai is a protohistoric site of about two hectares in north-east Afghanistan first excavated between 1976 and 1979 (Francfort 1983: 518). Although artefacts are locally made, they are Harappan in style, as are the building materials, seals and imports such as carnelian beads, there are also exports, such as locally mined lapis lazuli, which link Shortughai with the main Harappan region to the east as well as cultures to the west, though in later phases the culture becomes more insular (Francfort 1983: 518 to 519).

4.3.6 Post-Harappan, Trade with Rome

Latter-day maritime trade with Rome and the Gujarat's (Himanshu 2004: 49) should also be considered as further supporting evidence of east-west routes and trade relationships. Although there is already much useful evidence regarding the Harappan's trade with cultures to the west, one might also consider trade in the later historic period with Rome as evidence of the Indian sub-continent's importance in commerce. The trade between India and the Romans, long after the demise of the Harappans is mentioned in the *Periplus Maris Eryhraei*, (Casson 1989), that is, the Periplus of the Erytraean Sea is a handbook for merchants of disputed origin, written during the time of Nero (Warmington: 1974:15).

Warmington surmises that the west under Rome embodied the spirit of "energetic discovery" in contrast to the "little-changing peoples of the East" and this is the impetus for trading adventures from west to east during the time of Imperial Rome (Warmington 1974: 1). This scenario of trade initiated by the west has not always been so rigid and one-sided. In the trading relationship between Mesopotamia and the Harappans, movement was more dynamic in the other direction, that is, east to west, as is seen from the numerous Indus seals and trading goods found in the Persian Gulf and Mesopotamia, whilst almost nothing of Mesopotamia is found in the Harappan sphere except some minor material evidence and perhaps a little cultural diffusion in the form of fashion as can be seen in the bust of the "Priest King's" beard and hair-style, though even this is, of course, is a major assumption. It could be further argued that one of the reasons for trade being so one-sided is that the Indian sub-continent was almost completely self-sufficient and any short-falls in goods could be found nearer to home, such as lapis lazuli from Shortughai in Afghanistan.

Trade, although prevalent, for example, due to the demand for goods such as ivory, echoing the earlier Harappan period, generally took place through intermediaries. The Erytraean Sea is thought to refer to all oriental seas, that is, the Indian Ocean, the Arabian Sea, the Persian Gulf and perhaps the Bay of Bengal (Wheeler 1955: 141).

From the aforementioned *Periplus*, it is known that ships left Egypt for India in July to take advantage of the summer northerlies in the Red Sea. They travelled the Red Sea via

Bab el Mandeb through to the Gulf of Aden, the Arabian Sea, then to India, most likely to one of the later port cities of the Gujarat, such Barygaza or the mouth of the Indus River (Casson 1984: 190) to, most probably, the port city of Barbarikon (Young 2001: 28). The trade route that Young proposes, in fact, seems to have changed little from the earlier Harappan times when one examines the coast-hugging route via the Persian Gulf (Young 2001: 29). It is interesting to note that Casson concludes that in Roman times, although journeying to India by ship involved long, potentially dangerous passages over open water, the advantages of great profit outweighed the risks (Casson:1984:192). This strengthens the proposition that trade with India, particularly maritime trade has a long history due to the demand for eastern commodities and earlier maritime trading links between India, the Persian Gulf and Mesopotamia are, therefore, more likely. This is further confirmed by the work of Miller, again linking Barygaza with the Persian Gulf (Miller 1969: 144 to 145 and Map 5).

The trade relationship between Rome and India seemed to have reached its peak in the early empire period, c.1 AD to 200 AD. This was partly due to later political instability in the Roman Empire disrupting the viability of certain long distance trading routes (Greene 1986: 29 and 43). The lack of archaeological evidence of Indian ships reaching as far as the Red Sea (Greene 1986: 29) indicates that there was little demand for trade commodities from the west by the Indians. This would also follow the earlier relationship between Mesopotamia and the Harappans. The importance of east-west trade relationships can be gauged from the fifty to one-hundred million sesterces that Pliny estimated as the annual cost of eastern imports from Arabia, India and China (Potter 2006:287).

Again the importance of the Harappan region is emphasised with its geographical placement ideally placed as a contact point for civilisations further to the west including Rome.

4.3.7 Historic, Medieval and Pre-Colonial Trade

After the Harappan era, the first cities appeared again in the Gangetic plain at around the time of the Early Historic Period of c. 500 BC to 500 AD together with decipherable

writing and a similarity in material culture such as fortifications and cast currency in the form of copper and silver coins (Morrison 1997: 89 to 90). About two hundred years after this new era began at c.321 BC to 185 BC, the Mauryan empire came to the fore enforcing a huge territory of new and emerging states (Morrison 1997: 89). Trade became more prevalent again with various places acting as markets and ports, urban markets and Buddhist monastic exchange systems and sophisticated financial machinery indicates the resurgence of trade (Morrison 1997: 97).

Although the preceding time was not, by any means a commercial vacuum, there was a particular boost in trade during the Late Medieval period from 1200 AD to 1600 AD with an expansion of cities and a corresponding increase in agriculture (Morrison 1997: 100).

Therefore, the dynamism and sophistication that can be seen through most of the history of South Asian trade, further refutes orientalist notions, such as that of the aforementioned Warmington (Warmington 1974: 1), of a stagnant civilisation, in fact, material and documentary evidence indicate vibrant overseas trade in the days before the East India company and the later British Raj (Morrison 1997: 102 to 103).

4.3.8 Colonial Trade

A short comparison of Harappan ports with later colonial ports is now offered with a view to ascertaining the utility of using such a comparison as an example of how the ancient Harappan ports may have functioned.

Calcutta established in 1690, Madras founded in 1640, Bombay ceded from the Portuguese in 1664 are examples of ports that pre-date the founding of the British Raj in 1757 (Mitter 1986: 95). There are thought to be two basic models for urban growth- planned and organic or unplanned growth as a result of having to meet a particular requirement, unlike the Harappans, Mitter argues that European based cities did not possess a regular, planned format because the main motivation for urban development was profit rather than "glory" (Mitter 1986: 102). Other than the major cities mentioned above, small "factories", so-called because they provided accommodation for East India Company agents and factors (Mitter 1986: 101-102), such as the one in the Gujarat at Cambay (Lambourn 2002: 495),

can hardly compare with the monumental architecture of Harappan cities. This being the case it seems inappropriate to compare Harappan ports with pre-Raj Indian ports. Take Bombay as an example, where even links with the interior of the country remain undeveloped until the nineteenth century (Kosambi 1985: 37). The one tentatively proposed similarity between the colonial ports or cities and the Harappan ports or cities that can, at least, be conceived of is that the core fort area of colonial cities (Kosmabi and Brush 1988: 46) compares slightly with the strongly built "citadel" (Gates 2003: 71) of Harappan cities. In later British India though, perhaps a pale reflection of Harappan planning is evident and possibly indicative of how empires of commercial origin can develop into something somewhat more grand in terms of urban planning than what is possible at home (Keene 2005: 14-15).

As far as colonial trade practices were concerned, it is again difficult to envision a comparison between Harappan traders in the Gujarat or, in fact, any Harappan city or port and their British East India Company or Raj counterparts except perhaps when loosely considering the presence of Harappan trading colonies in Mesopotamia or Bahrain (Rao 1979: 224). This is because the post-1757 British imperial trade policy seems more purposefully and increasingly exploitative, particularly with respect to gross trade imbalances (Jones 1947: 70, Polak 1930: 236), than merely economic which appears to have been the main motivation of the Harappans.

4.4 Trade Commodities

It is thought that a ready market for goods in the west provided the impetus for developing integrated transport networks and ports and, therefore, the study of traded items that follows is an attempt to understand the primarily economic motivation for development of trade and exchange mechanisms in terms of commodities that may have driven supply and demand. Also, as will be seen, the transport of bulk goods west such as timber could only have been accomplished by ship and the evidence of bitumen loosely suggests a knowledge of water-proofing. In addition luxury items seemed to command premium desirability as an export.

4.4.1 Textiles

From the Harappan side, it is known that cotton was produced (Allchin and Allchin 1982: 191 to192) or at least signs of its everyday use have been found at Harappa. There are textile impressions on a toy bed made during the Harappan Phase, c. 2600 BC to 1900 BC at Harappa (Kenoyer and Meadow 2001b: Slide 115) which shows a finely woven cloth material fashioned from uniformly spun threads. There are also other impressions of textiles left on a fragment of terracotta (Kenoyer and Meadow 2001b: Slide 197) and the oldest; a small impressed fragment from c.3300 BC (Kenoyer and Meadow 2001b: Slide 114). Evidence can also be found at Mohenjo daro, Rahki Garhi and Chanhu daro (Ratnagar 2004: 108).

Tablets from Early Dynastic times, c.3000 BC to pre-Sargonid c.2350, indicate that southern Mesopotamia, while lacking mineral wealth, was a rich agricultural region and wool and goat hair were used to produce finished textiles, texts from Lagash also indicate that clothing was being taken to Dilmun (Bahrain) by sea where it is traded for Magan (Oman) copper (Ratnagar 2004: 107). This indicates that there was an exchange of goods between Iraq and Bahrain via Oman during this period. Though cotton was an obvious trade item with the Mesopotamians who had to contend with extremely hot summers, no evidence of it seems to exist at sites in Mesopotamia, the Persian Gulf or Iran (Ratnagar 2004: 108). Conversely, there may be evidence of wool and textiles reaching the Harappans as exports from Mesopotamia (Ratnagar 2004: 109).

Finally, an idea to consider, though still lacking evidence, is that perhaps the cotton was used for another purpose such as fishing nets; this conjecture is based on a similar use of cotton discussed later in this chapter in the examination of Caral (Shady 2001) as applied to the Harappan Civilisation.

So far, therefore, only the Iraq, Bahrain, and Oman maritime trade network can be established based on evidence of textiles, thus the use of textiles as solid proof of direct trade between the Harappans and cultures to the west is not yet viable at this juncture.

4.4.2 Food Stuffs

Dates were grown and particularly prized in Dilmun and Magan; date stones have been found at Mohenjo daro, though it is not certain whether they are domestic or imports (Ratnagar 2004: 110), thus are not useful as evidence of external trade.

Beginning in the same early period mentioned above, barley, flour and oil was shipped from Ur and Lagash to Dilumn, Magan and Elam (Ratnagar 2004: 109) also sesame oil (see also 2.5.10), wool and clothes were sent to Magan in exchange for copper (Ratnagar 2004: 107).

This does now suggest evidence directly linking Dilmun, or Magan with Meluhha and, at least, establishes half the route. This seeming lack of direct food exchange seems not to have survived to later Roman times when trade with India brings commodities such as pepper, aloe and other spices to Rome (Miller 1969:110, 35 and 37 to 38).

4.4.3 Bronze, Copper and Tin

With a scarcity of tin the Harappans produced implements of mostly unalloyed copper and some of bronze, though mostly of fairly low quality (Ratnagar 2004: 112). The bronze was either alloys of lead, tin or arsenic (Ratnagar 2004: 115). Copper was alloyed with tin, arsenic, lead and sometimes nickel with slight variations in the ratios of alloys between sites (Lahiri 1995: Table 2).

Arsenic and tin alloys were the two types of copper prevalent during the period; copper-arsenic alloy, arsenical bronze and, the more usual, bronze; an alloy of copper and tin, or sometimes a combination of all three were in widespread use in western Asia (Ratnagar 2004: 13).

The main sources of copper during this period was Cyprus, Anatolia in Turkey, the Zagros mountains of Iran (Ratnagar 2004: 119), Afghanistan, Oman and North-West India

(Ratnagar 2004: 21); all were large producers of copper. While sources of tin are thought to be the Eastern Desert of Egypt and Anatolia (Ratnagar 2004: 124), as well as Western Afghanistan and the possibility of tin from alluvial sources in India, such as as from the Punjab (Ratnagar 2004: 125).

Bun shaped ingots of both copper and bronze have been found in Mesopotamia, Susa, Bahrain, Oman and in the Harappan region at Chanhu daro, Mohenjo daro and Lothal (Ratnagar 2004: 117). Though there are no identifying ownership marks that link the ingots, the Susan ingots and the one from Lothal share a similar weight range (Ratnagar 2004: 118). Although, copper is known to come from Meluhha, it is assumed that this copper was loaded onto the ships of Harappan merchants at Oman (Ratnagar 2004: 127).

4.4.4 Gold

The precise location of the main source of gold for the Harappans is not known (Ratnagar 2004: 156), though gold of a similar type to Sumerian gold, that is, containing a high percentage of silver has been found at sites including Mohenjo daro and Lothal (Ratnagar 2004: 156, 157). These gold caches that have been found mainly consist of jewellery in the form of beads, hair ornaments, bracelets and earrings (Ratnagar 2004: 158).

A few beads have similarities in form to pieces found in Mesopotamia (Ratnagar 2004: 157). The main source of gold was Egypt, though this was only in the later Bronze Age (Ratnagar 2004: 155). The Black Sea area was prevalent in gold production (Ratnagar 2004: 157), but this was probably too far from the Harappans and thus most unlikely as a source of gold for them.

It, therefore, seems unlikely that gold forms a useful basis on which to build a case for intercultural contact, this, of course, does not mean that exchange did not take place, but simply that it is difficult to prove.

4.4.5 Silver

Before the Harappan period there is no evidence of silver in North-West India and after the Harappan period it disappears from early Indian history (Ratnagar 2004: 199). However, the Mesopotamians did send ships with silver to Dilmun as a trading item and it is entirely possible that the Harappans obtained it there (Ratnagar 2004: 200 and 314) and Larsa Dynasty texts from Mesopotamia, c.2025 BC to 1725 BC, also confirm the movements of silver east (Ratnagar 2004: 199).

4.4.6 Lead

Lead is present at Mohenjo daro and Harappa as an alloy of copper. Six percent of analysed copper tools contain between one and thirty two percent of lead. There are also a scattering of other small lead objects at other sites (Ratnagar 2004: 197).

Silver is a by-product of lead smelting and since most of the silver used by the Harappans was non-domestic (Ghosh 1990: 327) so the likelihood is that lead was also from an outside source, possibly Afghanistan (Ghosh 1990: 327) which probably meant overland trade. The high prevalence of lead is somewhat puzzling, as while up to one percent of lead improves bronze, higher levels may produce fairly inefficient tools (Tyler 2005a).

4.4.7 Wood

During this time South Asia contained a huge wealth of forests (Ratnagar 2004: 129), in contrast to Mesopotamia which did not (Ratnagar 2004: 128). Domestically, the Harappans probably used cedar, poplar (Ratnagar 2004: 129), mangrove, mulberry, date palm, ebony and oak (Ratnagar 2004: Table 2.1).

Since wood was plentiful, at least before the decline of the Harappans, and was in demand further west, the simplest way to transport this heavy and ungainly material was by boat (Ratnagar 2004: 314). Textual records of Ur-Nanshe of Lagash in the Early Dynasty,

Period IIIa, roughly c.3000 BC, records the arrival of boats loaded with wood (Ratnagar 2004: 129). The types of wood exported by the Harappans probably included mangrove for furniture and construction, mulberry for furniture, boats and chariots, ebony for temples and also date palm.

It is interesting to note that amongst the possible theories of Harappan decline include the diminishing of natural resources through overuse, for example, the use of timber in building, but perhaps another possible cause of deforestation was over-export of wood to Mesopotamia which was known for being poor in timber.

4.4.8 Bitumen

Bitumen, a viscous hydrocarbon (Ratnagar 2004: 140) is used primarily as a pitching agent with multiple uses in water-proofing (Ratnagar 2004: 140 to 141) and mixed with material such as dried plant material or grit it becomes asphalt (Ratnagar 2004: 140). Its use in sealing the "great bath" at Mohenjo daro (Ratnagar 2004: 141) supports its utility for waterproofing and may be an indication that the Harappans were well versed in its use as a sealing agent which is further evidence of their ability to build sea-worthy vessels for trade. It should be mentioned, however, that scholars such as Ranagar do not support this theory (Ratnagar 2004: 141 and 142) because the material appears rarely in the Harappan context (Ratnagar 2004: 141).

Bitumen was particularly important in the construction of wooden Mesopotamian cargo ships (Ratnagar 2004: 141) though it was available domestically (Ratnagar 2004: 140).

With bitumen available domestically to the Mesopotamians and the material rarely used or available to the Harappans, it seems unlikely as a trade item.

4.4.9 Pearls and Mother-of-Pearl

A heap of oyster shells has been found in a house in Mohenjo daro, however the type of oysters found in the region are not of jewellery quality (Ratnagar 2004: 143). Mother-of-pearl beads have also been found at Mohenjo daro and Chanhu daro; probably from the Persian Gulf as they are not present in the waters of Western Indian (Ratnagar 2004: 143).

Mesopotamian Early Dynasty burials often contain pieces inlaid with mother-of-pearl (Ratnagar 2004: 145). The Larsa Dynasty has records of "fish-eyes"; probably pearls imported from Dilmun (Ratnagar 2004: 143). The pearls imported into Mesopotamia were likely to be native to the extensive oyster banks of Bahrain (Ratnagar 2004: 144).

This indicates that the two cultures of the Mesopotamian and Harappans do interact, at least indirectly, in that they both appear to have obtained oyster shell products from the same place (Ratnagar 2004: 142 to 145).

4.4.10 Semi-Precious Stones: Carnelian, Agate, Jasper

Carnelian is found extensively in the Gujarat region (Theunissen et al 2000: 91) occurring both as yellow carnelian and, if the iron content is high enough, red carnelian (Ratnagar 2004: 146). There is archaeological evidence of bead manufacture at Lothal (Ghosh 1990: 217, Ratnagar 2004: Table 2.5), Chanhu daro and also larger Harappan cities such as Mohenjo daro and Harappa amongst others (Ratnagar 2004: Table 2.5). For instance, at Harappa in Period I, 3300 BC to 2800 BC, there is evidence of bead manufacture from carnelian, agate and jasper (Kenoyer 1997: 267).

There is also strong evidence that finished etched carnelian beads found in Mesopotamia were of Indian origin; there are several reasons for this. The patterns on the beads, both the Harappan ones and those found in Mesopotamia match, though the patterns are not typically Mesopotamian design in origin (Ratnagar 2004: 178). Additionally Mesopotamian texts confirm that Meluhha was an important source of carnelian (Ratnagar

2004: 144, 145). Finally, further evidence of trade between Mesopotamians and Harappans is that both cultures seem to have quite different values in that etched carnelian beads are used as grave goods in Mesopotamian, Turkmenia, north-east and south-east Iran, but not once do they occur in Harappan graves (Ratnagar 2004: 185). Thus, when considered together with the large deposits of carnelian found in the Gujarat (Potts 1993: 389), it may be that the beads that were being produced were primarily destined for export from the Harappan Gujarat region to Mesopotamia and other areas, rather than for domestic use.

4.4.11 Vessels, Containers and Pots

Marble and calcite vessels were produced locally (Ratnagar 2004: 151) and are, therefore, a good argument against diffusionism.

While Mesopotamian vessels were, for the most part, finely wrought, those of their Harappan counterparts were fairly crude (Ratnagar 2004: 151). However, carved stone bowls ranging from Mesopotamia to Mohenjo daro do share a similar decorative style (Lamberg-Karlovsky 1975: 350). Lamberg -Karolovsky is, however, reluctant to consider these bowls as substantial evidence of trading links between the two cultures, that is, Mesopotamia and the Harappans, due to this same, seemingly over-abundance of similar artefacts throughout these regions and laboratory testing cannot, at least at the time of writing, determine many of the sources of this material (Lamberg-Karlovsky 1975: 353).

As for pottery, while there is some evidence of similar typology across the region in its manufacture, there is no evidence that they were transported as trade items trans-regionally; the typology can, possibly be explained by cult, fashion or nomadic artisans (Ratnagar 2004: 178).

The finely designed Harappan red polished slipware is distinct to the Gujarat area (Orton: 1991: 46) and its survival continued into the later historic period and well into the fifth century AD (Begley:1991:176), hence, illustrating the decline of the Harappans rather than their cultural extinction, in fact, though it is available throughout historic India, its quality

is highest in the Gujarat suggesting the survival of a strong Harappan imperative, at least in the form of continuation of design and workmanship.

4.4.12 Dark Stone

Diorite and dolerite are hard dark stones, volcanic in origin (Ratnagar 2004: 153). In the Harappan context it appears as mace-heads at Chanhu daro and Mohenjo daro (Ratnagar 2004: 153), though Ratnagar believes that the Harappans did not have much use for it in general (Ratnagar 2004: 154).

However, it was much valued by the Mesopotamians (Ratnagar 2004: 152) who used it in statuary (Ratnagar 2004: 152) and tools (Ratnagar 2004: 153).

It probably comes to Mesopotamia from Oman, though it is mentioned in cuneiform texts once as coming from Meluhha (Ratnagar 2004: 153).

4.4.13 Pigments

The Harappans used red ochre to paint pottery and terracotta figures and possibly in funerary rites. Red and yellow ochre is available locally in the Kutch area of the Gujarat (Ratnagar 2004: 154).

Red ochre is not native to Mesopotamia, but was imported from Dilmun, though it was probably brought to Dilmun from another location as it was not native to that island either (Ratnagar 2004: 154), though a good local source could be Hormuz.

4.4.14 Ivory

Ivory in Harappan sites is a frequent find though many objects are utilitarian in nature rather than purely decorative, for example, combs (Ratnagar 2004: 162) and Indian ivory is of a type far superior to African for carving and finishing (Ratnagar 2004: 159).

Mesopotamian texts from the Third Dynasty of Ur c.2500 BC, only mention it coming from Dilmun except in the case of carved birds from Meluhha (Ratnagar 2004: 160).

4.4.15 Lapis Lazuli

At Harappa in Period I, 3300 BC to2800 BC, evidence of bead manufacture from lapis lazuli can be seen (Kenoyer 1997:267), also at Mohenjo daro, Chanhu daro, Lothal, Dholavira and other Harappan sites, lapis occurs in ornaments, though more commonly in beads (Ratnagar 2004: 189).

Lapis lazuli was used extensively in the Mesopotamian world; ornaments, cups, statuary, seals, amulets are some of the objects found both for ceremonial and personal use (Ratnagar 2004: 192).

The largest source during this period was located in Badakhshan, Northern Afghanistan, with the Harappans probably supplying it to the Mesopotamians, probably via Dilmun in the post Early Dynasty period of Mesopotamia (see 4.3.5 Trade Colonies, Ratnagar 2004: 190).

4.4.16 Shells

Shell was used as decoration and inlays in both cultures (Ratnagar 2004: 200).

Most Indian shells were probably locally sourced, the rest were probably from the Gulf of Oman and Muscat (Ratnagar 2004: 201), which is probably also the source for the Mesopotamian shells (Ratnagar 2004: 202) though there are some interesting exceptions.

Shankh, more commonly known as conch shells, that is, of the genera *Strombus* and *Cassis* are common to South Asian waters; these were exported to Mesopotamia and used for large cylinder seals in the Royal Cemetery at Ur (Ratnagar 2004: 202).

4.4.17 Monkey Figurines

Although there are no monkey species native to Mesopotamia, it is likely that India was the nearest source of live monkeys, possibly as pets and carved figurines and there are monkey figurines at Harappan sites, though the monkeys in Harappan art more accurately depicted than those in Mesopotamian art simply because the Harappans were more familiar with them (Ratnagar 2004: 203).

Monkeys, while not native to Mesopotamia were an important aspect of Mesopotamian art and from the Early Dynasty to the Larsa period they can be found as figurines at Mesopotamian sites (Ratnagar 2004: 203). In a Larsa period text there is one carnelian monkey figurine mentioned which was likely to have come from Meluhha (Ratnagar 2004: 203).

Hence, monkey figurines are also a good indicator of east to west trade between the two cultures (Ratnagar 2004: 203-207).

4.4.18 Weights

Further proof of trade between the two cultures is that a Harappan weight, of the type mentioned before (see 2.5.3) has been found at Ur during Ur Period III (Ratnagar 2004: 249); "it has an almost exact counterpart...at Chanhu daro" (Ratnagar 2004: 250) a Harappan site (see also 4.2.8).

4.4.19 Seals

As well as the round Harappan seals found in Bahrain and mentioned earlier (see 2.5.4) and, of course, the seals found in the cities of the Harappan culture, Harappan seals have also been found in Mesopotamia.

Both at Kish in an Early Dynastic context and at Ur, a Harappan seal has been found (Ratnagar 2004: 259), a cylinder with Harappan bull signs has been found at Susa in Iran and various others have been found at Telloh (Ratnagar 2004: 260). Early Kassite levels at Nippur contain another bull-type seal, there is a common "unicorn" seal in the Iraq Museum and a square bronze seal found in a royal grave at Ur probably from the Akkadian period (Ratnagar 2004: 260).

While the Harappan square shaped seals differ from Persian Gulf seals which are round or Mesopotamian which are cylindrical, they were most likely used for the same purpose, that is, to identify ownership of goods (Lamberg-Karlovsky 1975: 362).

4.5 Trade Simulation

It is hoped that the previous section has illustrated that certain commodities were exchanged between Mesopotamia and the Harappan Civilisation and, particularly in order to graphically illustrate the evidence of these exchanges, it has been decided to model the various trade flows given a specific mode of transport using the agent based programming

language StarLogo (MIT Education 2005, Appendiz A: hartrade.slogo). Before launching into the model, a brief history of agent based modelling and its application to archaeology is offered.

An agent based modelling environment is designed to model decentralised systems. The philosophy behind decentralised systems is a result of the synthesis of chaos theory, complexity theory and the idea of self-organising systems, that is, systems without central control. This is in direct contrast to the Newtonian idea of each cause having a direct and opposite effect. This can be particularly seen in complicated systems that seem to conform to a pattern without any outside control such as flocking birds, shoals of fish and social systems. All these systems completely defy explanation in a Newtonian only universe.

By "agent based", it is meant; any programming environment such as StarLogo (MIT Education 2005, Colella et al 2001), Swarm (Swarm 2009) and NetLogo (NetLogo 2009), amongst others, that allows the programming of agents that are autonomous because they can make decisions for themselves, and adaptive in that they can respond to challenges. In StarLogo these agents are known as turtles and can represent various complex systems from immune cells to human beings. StarLogo is an offshoot of the Logo programming language (Harvey et al 2008), itself a subset of LISP (McCarthy et al 1962), but unlike Logo, StarLogo is massively parallel, that is, the user can program not just one or a few, but thousands of turtles. The construction of the programming environment, that is, the simulated virtual world with creatures that act autonomously can be traced back to a non-computer rules-based board game called the "Game of Life" designed by the Cambridge mathematician John Horton Conway to simulate evolving life (Gardner 1970 120 to 123).

The original drive to develop these kind of environments was to assist in investigating complex or self-organising systems by simulating them using cellular automata; artificial autonomous cells, for example, in order to model evolutionary theory. It is now apparent that the software tools created to study these phenomena can be used to model almost any complex situation where complicated interactions takes place. This means that whether the field is biology and the study of social insects or sociology and the study of social interactions between human beings, interactions can be modelled graphically and mathematically.

And it is here that its use finally enters the world of archaeology with the development of models such as the artificial Anasazi model using the SWARM development environment (Kohler 1996). Kohler's research seeks to explain interactions in an Anasazi village, subsequent work (Axtell et al 2002) seeks to explain growth and collapse of an Anasazi populated valley.

In fact, between 1997 and 2001 there have been fourteen land use cover change research projects using a combination agent and cellular models (Parker et al 2003: Table 1), though as this type of model is outside the scope of the main thrust of the research only one case study is summarised in order to present a clearer picture of the field and to enable an understanding of the simple prototype system that has been developed here as a demonstration of the ease with which such models may be built and why such a model may assist in furthering the cause of Harappan research in general.

4.5.1 Case Study, Multi-Agent Modelling: Multi-Agent Model of the Kayenta Anasazi

The researchers have based their study in the Long House Valley of the Black Mesa area of North-Eastern Arizona in the United States of America (Axtell et al 2002: 7275). From c.1800 BC to c.1300 AD this region was inhabited by the Kayenta branch of the Anasazi people, the prehistoric ancestors of the modern Pueblo cultures of the Colorado Plateau (Axtell et al 2002: 7275). Approximately between 7000 BC and 1000 BC, the valley was sparsely occupied, first by palaeoaboriginal hunters of large game and later by hunter-gatherers, then the introduction of maize at c.1800 BC started a long transition to the Anasazi cultural tradition and a food producing economy which lasted until the abandonment of the area at c.1300 AD (Axtell et al 2002: 7275). "Anasazi" is the name used to identify a distinctive archaeological pattern and sequence that is limited to the geographical area of the southern Colorado Plateau and that has led to the cultural characteristics that define the modern Pueblo people (Axtell et al 2002: 7275). Anasazi patterns are defined by ceramics such as black-on-white painted pottery, plain and textured gray cookware and the development from pit-houses, stone masonry, adobe pueblos and the kiva circle as the main ritual construction. However, there is a recognition of several

geographic variants of Anasazi; Long House Valley is of a western Anasazi type (Axtell et al 2002: 7275). Long House Valley is physically isolated on a Navajo reservation in North-Eastern Arizona, which enables a practical test of the ability of agent based models to interpret settlement patterns and population behaviour amongst subsistence-level agrarian societies in harsh environments (Axtell et al 2002: 7275). A combination of natural sciences including geomorphology and dendroclimatology, amongst others, has enabled an accurate reconstruction of changes to yearly agricultural production in terms of kilograms of maize per hectare and the archaeological record of Anasazi farming communities from 200 AD to 1500 AD also provides data about one thousand years of social and cultural development (Axtell et al 2002: 7275).

The researchers believe that archaeology is the only science that can access data of sufficient duration to reveal long-term changes in the pattern of human behaviour (Axtell et al 2002: 7275). Although archaeology has traditionally been concerned with the interpretation of how societies change and develop in the face of response to fluctuating conditions, a major problem to rigorous research is the inability to perform reproducible experiments, a problem which also faces other sciences, such as astronomy, geophysics, and palaeontology (Axtell et al 2002: 7275). This is the reason to consider computer based models as a way of by-passing these obstacles and, therefore, within anthropology and archaeology there is an interest in agent based modelling which are models consisting of populations of single units of artificial, autonomous agents which live in digital spatial landscapes where each agent can be an individual, household or a clan with particular attributes such as life span, food needs, movement capabilities and family ties (Axtell et al 2002: 7275). A set of rules of behaviour defines way in which agents interact with their environment as well as each other; histories are developed in these types of models by activating each agent periodically and allowing them to interact (Axtell et al 2002: 7275). Agent models, therefore, allow various possibilities for overcoming the experimental challenges of archaeology through an analysis of these alternative histories of social relationships and behavioural responses by changing the attributes and rules of the agents and features of the environment they exist in (Axtell et al 2002: 7275).

Thus, the team has built a multi-agent computer model that is closely based on this society in terms of its history, population and spatial settlement pattern fluctuations and final

sudden collapse (Axtell et al 2002: 7275). In the model, the agents are mono-agriculturalists, that is, they only grow maize and they autonomously determine the location of their fields and settlements (Axtell et al 2002: 7275). Availability of food imposes limits on fertility (Axtell et al 2002: 7275). Differences in individual agents, though, difficult to mathematically model, are shown to be vital to the success of the model (Axtell et al 2002: 7275). The model is constructed by simulating an artificial landscape from variables created from data concerning the palaeoenvironment which is then populated by artificial agents representing either families or households (Axtell et al 2002: 7275). The household agent is based on data concerning population and food requirements obtained from ethnographic research of historic Pueblo groups over time as well as other subsistence farmers (Axtell et al 2002: 7276). Whereas the family agent is defined by other data attributes including age, size, composition and amount of maize storage. Agents also have particular rules governing behaviour which determine the choice of household agents in selecting both planting and dwelling locations (Axtell et al 2002: 7276). When all agents are initialized, the computer model begins to run based on internal clocks (Axtell et al 2002: 7276). One clock decides what the life-span of a household is, based on the rule that when a daughter marries at sixteen she will form a new household and another clock simulates maize consumption based on the number of individuals in the household (Axtell et al 2002: Table 3). All agents engage in agricultural activity during each year and move their planting or dwelling locations or both based on their ability to meet food requirements (Axtell et al 2002: 7276). The simulated dwelling and planting locations and community size, determined by the number of households at each site, are graphically updated as a map which runs simultaneously with another map of real archaeological and environmental data so that both the simulated population dynamics and residence locations, together with the real ones, may be visually compared (Axtell et al 2002: 7276). Graphs also show real and simulated statistics for population, location and sizes of dwellings, maize quantities and fluctuating household numbers (Axtell et al 2002: 7276 to 7277).

The researchers have also changed an earlier model to include larger differences within both agents and landscape, while in the previous model all agents have the same ages for the events such as fertility and death, now each agent has a specific value for these ages (Axtell et al 2002: 7277). This is also the case for rates of household division at the time

of daughter marriages. In addition, production factors are treated as an adjustable variable based on the average harvest per hectare and the size of the harvest (Axtell et al 2002: 7276). It has been found that, bearing in mind smaller fluctuations over time, the simulated population numbers closely resemble historic population numbers and while the ability to predict site locations of settlements varies, the real movement north of the population over time has also been reproduced in the model (Axtell et al 2002: 7278). The real Long House Valley was abandoned after c.1300 AD; even though the model suggests that the worsening environment could have support a smaller population in the northern part of the valley (Axtell et al 2002: 7278). This indicates that the degradation of environmental factors induced a behavioural critical mass leading to the final abandonment (Axtell et al 2002: 7278). Finally, the researchers believe that it may be useful in future simulations to model interactions between population, environment and disease to test whether a combination of these push-factors may have led to abandonment and although the model built by the researchers is made of facts and data, it still manages to produce simulated results that are confirmed by historical records (Axtell et al 2002: 7278).

4.5.2 Agents, Harappans and Trade

Interestingly, although the main focus is the discovery of new Harappan port sites, there does remain the similar puzzle of the decline of the Harappan Civilisation. Perhaps future archaeologists may also decide to use decentralised modelling to further investigate this event. One could even go as far as saying that agent based modelling techniques applied to ancient trade are particularly suitable, given that ecological models are often simulated using the same technology and ecological systems are very similar to trade models due to the focus on spatial distribution of natural resources common to both natural ecosystems and artificial ecosystems (Chang:1975:211). Thus, trade can and should, perhaps, be studied with the mindset of an an ecologist and, if this is to be the case, there is no reason why those studying trade should not use the same tools available to the ecologist.

4.5.3 Harappan Multi-Agent Transport Model

And so on to the model of Harappan trade exchanges. This is a fairly simple model that demonstrates trade mechanisms between the respective Harappan and Mesopotamian cultures and also the relative simplicity involved in building basic models.

The program is designed based on the following rules and because, as has already been seen, the largest volume of trade is supported via maritime transportation routes-

> A large amount of goods can be transported fastest over water, that is, by boat or ship.
>
> A medium amount of goods can be transported at a slower pace over flat land, that is, using Harappan type bullock carts.
>
> A small amount of goods can be transported at an even slower pace over mountains, that is, by use of pack animals.

Movement is controlled autonomously in the code by each agent or turtle which represents one of the above modes of transport. Each agent can only move forwards, but randomly and at a pace determined from the above rules.

The agent based program (Appendices: hartrade.slogo) demonstrates the premise that maritime transportation is faster than carts and carts are faster than pack animals, hence the importance of ships to Harappan and Mesopotamian trade interactions.

The flow digram that follows explains the basic steps that the agent program follows.

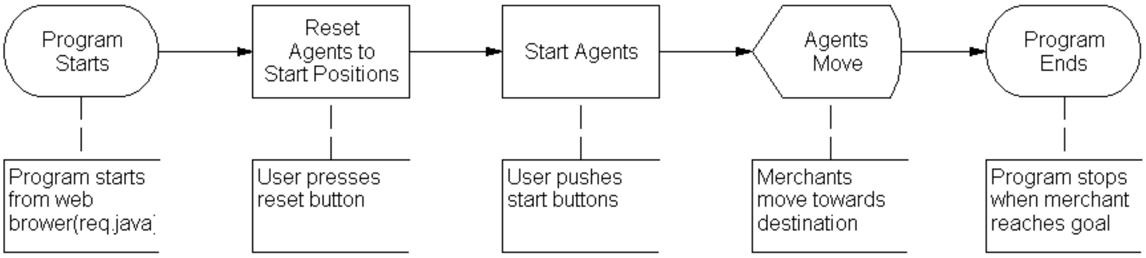


Figure 4.1 Agent Based Trading Model

And overleaf is a screen shot of the actual program in action.

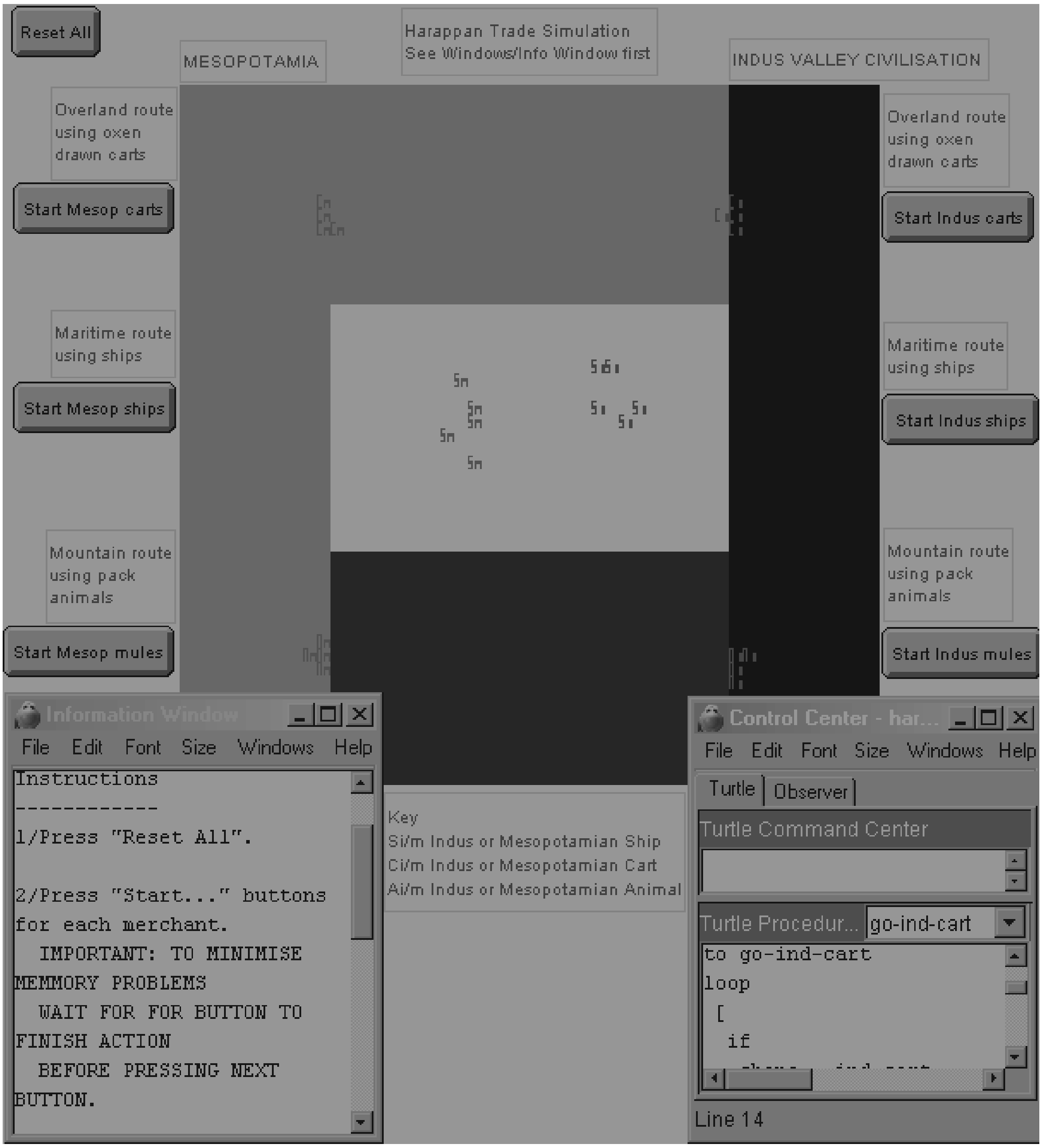


Figure 4.2 Trade Simulation

4.5.4 Critique

The model is simple and, though time-consuming to build, it does graphically explain the textual description greatly.

This model is only a brief glance into the power of agent based programming. It is a an example of what is achievable today using agent based programming tools. For future research of the Harappan Civilisation concerning topics such as Harappan social dynamics and the demise, further use of such tools may prove particularly valuable.

In fact, more general benefits can be seen where research attempts to solve current archaeological problems, such as the need to examine social processes at the bottom of hierarchies as well as the top, in order to understand cultural evolutionary trends which retrospective analysis allows archaeologists to discover in human history (Renfrew and Bahn 2005: 39). The agent based approach is thought to be one of the most hopeful, where the interactions of entities, or agents, attempting to achieve local goals lead to unexpected results at different scales of both time and space, including the formation of new social institutions (Renfrew and Bahn 2005: 39).

4.6 Trade Transportation

It has been thought that sea trade was important in terms of economic and social prosperity of the Harappans and as an impetus for the growth of their civilisation.

Given that trade was so important to the Harappan Civilisation, it is, therefore, important to look at the methods Harappans used to move goods to and from their trading partners.

4.6.1 Vessels

Although pack animals and carts suffice for small loads, as can be seen from the agent based model, the best way to move goods in bulk is by sea. Simply put, seagoing vessels can carry more, further and at less cost than land transport using animals. It may also be useful to consider that a course across the sea would have also have avoided several large and hazardous mountain ranges.

Add to this the fact that many of the more important Mesopotamian and Harappan cities were accessible via sea and river and a journey across the water is generally the shortest distance, maritime transport was probably the most important component of intercultural contact through trade exchanges. Recent evidence at Oman supports this and thirty two percent of the pottery excavated recently at Asimah in Oman are from the Harappan region (McGrail 2001: 251).

One might also consider that the Harappan and Mesopotamian civilisations were separated by the Elamites; the Mesopotamians and Elamites had a long history of enmity, therefore, it is "possible that the development of sea trade was brought in Mesopotamia through a necessity to bypass overland routes through hostile Elamite territory." (Lamberg-Karlovsky 1972: 228).

However, sailing is not without its disadvantages. The south-west monsoon season lasts from May to August, with sailing hazardous until, at least, November, though December to early March would be favourable with the monsoon occurring in late March (McGrail 2001: 250).

With this heavy reliance on the boat as a means of transportation of bulk goods, the true picture of the importance of the Gujarat now becomes apparent. Its western bulge extended dramatically into the Arabian Sea, serving as access for the southern portion of Harappan Civilisation to the source of the richest consumer society at this time Mesopotamia to the west.

Also, in terms of riverine cargo transportation it also seems obvious that boat-building must have been a skill practised by the Harappans. Emphasising this point, Ernest Mackay states, "Boat-building must also be included among the crafts of a people whose chief interest was trade and who had, in Mohenjo daro, a prosperous city close to a large and navigable river" (Mackay 1935: 175).

Possehl states that there was a "revolution (or at least significant change) in maritime technology" by the time of the third millennium BC. He goes on to say that the technology was exploited as a means of economic advancement (Possehl 2002:215-216).

The subject of boats, ships and shipbuilding is, therefore, of great relevance in this research, because it assists in the determination of the physical characteristics of the landscape of ports and harbour areas in the region of study. That is to say, that by understanding the kinds of vessels used it may be possible to further understand the landscape requirements of such craft in terms of ecological features such as types and quantities of wood (see 4.4.7). Thus, the availability of wood and the natural geography, such as beach slope gradients (Tyler 2006) may have moulded the designs of Harappan vessels.

However, attention is now focussed on the various types of boat design available during the period.

<u>Reed Vessels</u>

Reed boats of Sorghum halepensis- a grass with long, hollow, buoyant stems are still used in the Gulf of Kutch today (Ratnagar 2004: 216) and a Mohenjo daro seal, implies a non-displacement reed craft of a type still used by marsh Arabs in modern Iraq and by the ancient Egyptians. Similar, in fact, to the *Tigris* vessel of Thor Heyerdahl which itself was, of course, modelled on ancient reed boat designs as an experiment of seaworthiness.

Though the similarity of reed boats across different cultures is most probably due to parallel technological evolution and not cultural contact or diffusion, a reed boat is a

natural evolution from a cruder raft, however, it still indicates that the shape of the Harappan boats can be determined by studying reed boats of other cultures.

Very early evidence of the use of reed boats can be seen in the Persian Gulf. Pieces of bituminous amalgam, many with the impression of reeds and with barnacle encrustations are almost definitive proof of reed boat-building in the general area (Carter 2005:53).

In 1978 the Norwegian anthropologist Thor Heyerdahl built the reed boat *Tigris*, which he sailed from the Tigris river in Iraq to the Indus delta in Pakistan and out on to Africa. The intention of this project was an attempt to prove the possibility of Mesopotamian-Harappan migration and, though this theory has now been discounted, it does prove that vast sea journeys in reed boats were possible.

<u>Wooden Vessels</u>

There was also another type of vessel; a wooden boat with sails and the various depictions of Harappan wooden boats show that they were narrower than their Mesopotamian contemporaries.

Unlike the Mesopotamians, the Harappans had no shortage of timber for building wooden ships. The forests were rich with many suitable woods such as teak and cedar, both oily traditional shipbuilding material, in fact, it has been stated by other researchers that "teak wood is always the best for ship and boat building and is preferred in Bombay" (Agrawal and Lalit 2004). And further attesting to the value of teak, even today, in modern Karnataka "Teakwood is used rarely because of its high cost." (Agrawal and Lalit 2004). Bamboo is also useful for masts and all these woods have been found at Harappan sites (Ratnagar 2004: 216).

It is also known, from the great bath at Mohenjo daro, that bitumen was used as a waterproof sealant, so it seems entirely likely that the Harappans would have known it as a useful pitching and caulking material.

From contemporary sources, it is known that, in general, the types of wood utilised in the construction of vessels included, for example, in Andhra Pradesh are grannari karra (*Egesa: Acquicia canilotica*), arcini karra (*Melia dubia*), cinntha karra (*Albizzia sp.*), rai karra, teak, circini karra (*Anogeissus sp.*), mamidi karra (Mango: *Magnifera indica*), sal (*Shorea robusta*), Indian laural (*Terminalia tormentosa*) and maddi (*Alianthus malabarica*). (Agrawal and Lalit 2004).

In modern Karnataka, the type of wood used for shipbuilding is known as kshatriya and the common types of wood used for shipbuilding are matthi, sagouy, teak, honne, undi and hebbals (Agrawal and Lalit 2004).

<u>Vessel Designs</u>

Mesopotamian literature refers to boats by the country of their origin, implying that boats were varied and of many different designs (Ratnagar 2004: 213).

The major stumbling block here, unfortunately, is that there is very little archaeological evidence of the types of boats used by the Harappans. Given the extreme age and the organic nature of the materials used in construction, the vessels themselves have long since decomposed.

There are a few clues, however, from depictions on seals, some models, toys, art, technological and material resources available at the time, other contemporaneous cultures and finally ethnoarchaeology to fill in the gaps and assist in building a blueprint for the most likely types of vessel used by the Harappans.

It would be fairly safe to assume, at least as far as trade is concerned, that there are perhaps two main types of boat that concern this research. The types of vessel probably consist of a general very low displacement flat-bottomed cargo vessel for river cargo and heavier displacement seagoing vessels. Additionally there were the small fishing and transport craft that probably abounded in this ancient riverine environment, perhaps similar to the old *shikara* design of small boat still used on the lakes of Kashmir today.

The form of these boats probably varied depending on the materials available, the wealth of the owner and their general purpose.

Riverine Vessels

Of course, flat bottomed craft have always been popular in estuary and river craft where there is always a danger of grounding. This being the case, it seems likely that the less sophisticated, inexpensive reed and flat-bottomed boats were for local transport.

Examples of such craft still abound in the region today where a variety of flat bottomed boats can still be seen. Basil Greenhill describes a photograph of a large flat bottomed cargo vessel and states that "One of the advantages of the type of vessel is shown by the fact that although quite a large vessel, she draws so little water that she can discharge her cargo straight on to the gently shelving river shore" (Greenhill 1976: 67, Figure 22).

The shape of these flat-bottomed river vessels today range from canoe to punt shaped, mostly double-enders, that is both fore and aft ends of the boat are similar in shape.

Maritime Vessels

The heavier seagoing wooden boats carried large cargo shipments farther afield, perhaps as far as Mesopotamia, and at least as far as the Persian Gulf.

With their high prows and sterns, shallow drafts and sails these craft could travel long distances and still have the versatility to travel up and down rivers on their way to or from coastal waters. It should also be noted that, although radically different in design and form, the Viking long-boats of much later history seemed to follow the same rules of construction for generally the same reasons.

A clay model from Eridu (Ratnagar 2004:220), graffiti (Ratnagar 2004:217) from Mohenjo daro and a clay model from Lothal (Ratnagar 2004:218) indicate a heavier displacement vessel, with a more rounded bottom. There also appears to be a mast with a yardarm and steering oars.

Sails

A clay model boat from Lothal shows a square-rigging (Ratnagar 2004: 219: Fig. 3.3). This style remained popular until past the age of the Romans and though its use somewhat lessened with time, there are still examples of its use well into the nineteenth century (Brogger 1951: 179). The reason for this, is although vessels equipped in this way can only sail with the wind mostly directly behind them and thus compare unfavourably with the lateen or modern Bermudan rigs, they do, however generate very great power, ideal for moving large loads. A gulf seal (Ratnagar 2004: 219: Fig. 3.4) clearly shows the broad yard-arm bisecting the perpendicular of the mast top from which two sailors appear to be unfurling a sail.

Oars and Rowing and Steering

From the appearance of the vessels and the evidence regarding sails above, it appears that seagoing maritime vessels were largely sailed. Again looking at this rather sparse evidence, steering appears to have been accomplished from the use of one or a pair of steering oars attached to the stern of the hull. There is graffiti from Mohenjo daro illustrating this arrangement (Ratnagar 2004: 217: Fig. 3.2).

Boat Fastenings

Iron was not used in third millennium BC for boat fastenings such as for pins and joints; instead fibre, cane and wood was used (Ratnagar 2004: 222). Examples of wood used for pins can also be seen from the modern era of this region (Greenhill 1976: 68).

Anchors

As can be seen throughout the research, there is evidence of pierced stones at Lothal that may prove to be anchor stones (Allchin and Allchin 1982: 173, Rao 1973: 50, Gaur and Vora 1999), though they also resemble millstones or, perhaps, the counter-weight component of a shaduf (Leshnik 1968: 917). These possible anchors can also be seen at

Kuntasi (Gaur and Vora 1999), Beyt Dwarka (Gaur, Sundaresh and Tripati 2005, Gaur, Sundaresh, Tripati, and Bandodkar 2005) and Kindar Kheda (Gaur and Sundaresh 2005). However, the stone anchors at Beyt Dwarka have been dated to the Medieval period (Gaur and Sundaresh 2003: 57 and 65). .

Cargo Capacity

In modern Pakistan Basil Greenhill has noted the construction of large cargo vessels of a flat-bottomed type perhaps used in Harappan times (Greenhill 1976 : 67: Figure 22 and 68). He states that on the banks of the Indus at Sukkur, he has watched as the two sides made of planks joined by wooden pins are assembled. Then a row of floor timbers, similar in form to railway sleepers, has planks attached to it, this is then turned over and then attached to rest of the boat. He states that this box shape structure leads to a very strong vessel "admirably suited to her environment and purpose, which is to be a great cargo carrier on the River Indus". Another plate showing this type of vessel in use gives some idea of the cargo capacity (Greenhill 1976: 67, Figure 23); it shows seven men spanning the stern of the vessel and conveys the impression of high capacity, both in terms of volume and weight. Also, from contemporary examples of Arab dhows, an estimate of in excess of one hundred tonnes is not unreasonable (Ratnagar 2004: 227).

Navigation

The simplest form of navigation from the Harappan region to the Gulf and beyond would have been the dead-reckoning technique (Murrant 1995: 141). By this, it is supposed that the captain would keep the coast of the Gujarat and then Baluchistan to starboard on their out-ward journey and then to port on the return. There was also the possibility of using lead lines, area specific sea colour and species of fish, plankton or birds as well as characteristic land-marks (Ratnagar 2004: 231).

Contemporary Examples

Ratnagar also sees parallels between the Lothal clay model and the more modern *pardav* vessel used on the west coast of India with its "rounded stern" as perhaps somewhat

analogous to bronze-age boat technology of the region (Ratnagar 2004:220). These keeled, planked boats are common in Andhra Pradesh both locally and also along the Andhra coastline. In Andhra these traditional boats are constructed at Nellare, Prakaram, Godavari and Guntur districts. (Agrawal and Lalit 2004).

Quoting S. R. Rao's detailed worked at Lothal, Agrawal and Lalit go on to state that the docking facilities at Lothal allowed ships of eighteen to twenty metres long and four to six metres wide and that at least two ships could simultaneously pass and enter easily. In the second area of docking facilities, the inlet channel is more narrow and though it could accommodate large ships, it could only allow passage for one flat bottomed vessel (Agrawal and Lalit 2004).

4.6.2 Carts

Bullock carts would have been used for very short transportation and general agricultural use and the same type of bullock carts that the Harappans used (Allchin and Allchin 1982: Fig. 7.17) are used in the region today. More convincingly, however, is Pre-Harappan evidence from c.3,000 BC in peninsular India of *anchylosis* (stiffening) of the hock joints in cattle. This is most commonly associated with livestock that have been used as pack or draft animals (Hutchinson 1976: 131).

4.6.3 Pack Animals

The main pack animals of the Harappan region was the onager, *Equus hemionus*, and the ass, *Equus asinus.* The bones of an onager have been found at Surkotada and those of an ass at Kalibangan. There have been claims that the horse, *Equus caballus*, was also present as there are terracotta figurines of horses found at Lothal. Many of the largest Harappan sites, including Mohenjo daro and Harappa have camel bones, but whether they were Dromedaries, *Camelus dromedarius* or Bactrian, *Camelus bactranus* is still in question. (Possehl 1999: 185-186).

4.7 Trade as a Mechanism for the Development of Civilisation

As this research concerns determining the validity of the existence of Harappan ports subsequently trade, trade routes and the importance of trade to the Harappans, it is perhaps useful to briefly note the ongoing debate amongst Indologists regarding a possible lack of evidence for the presence of warfare in Harappan Civilisation, whilst at the same time there appears to be a wealth of evidence suggesting the importance of trade.

Views that consider a lack of war include the work of researchers such as McIntosh who postulate a peaceful utopia (Macintosh 2002); Kenoyer, in a review of this work, although agreeing with the lack of evidence for warfare, still acknowledges the possibility of the existence of internecine struggles (Kenoyer 2003: 378). Others, such as Cork state that the lack of weapons in the archaeological record may not differ so much from quantities of war related artefacts present in regions where war is known to have existed (Cork 2005).

These conflicting views are reflected in the greater question in archaeology as a whole where the question of war as an impetus for cultural evolution (Haas 1998, Haas 2001) has recently been drawn away from war to perhaps trade (Shady 2001, Shady et al 2001: 723-726). Researchers such as Lamberg-Karlovsky also state that "one of the important `intensifiers' motivating the parallel, but essentially distinctive, rise toward urban complexes in Mesopotamia and the Iranian highlands, and the later Harappan Culture is trade" (Lamberg-Karlovsky 1972:229).

While these questions remain unanswered more outré views of Harappan society seem to come to light such as the rather dystopian view of Harappan culture ventured by Chakraborty (Chakraborty 1983). In the future it is hoped that more objective methods may assist in answering these questions. For example a GIS viewshed analysis, where factors such as "line of sight" may assist in determining the defensive capability of settlements (Jones 2006: 523). Or perhaps cross-cultural comparisons may also provide a useful method for understanding the archaeological record (Peregrine 2001: 15).

It should be noted, however, that if a systems or holistic view is taken, it is more likely that trade is only one of many aspects, equally important to warfare and various other political, social and industrial factors that may have influenced the development of societies (Edens 1992: 134).

Taking all these views into consideration, it is the opinion formulated during this research that there is at present not sufficient evidence to support either side of the argument at present. From a purely subjective standpoint, it is thought that trade, whilst not the sole driver of Harappan development was an important factor.

4.8 Harappan Period Trading Networks

Harappan trade, as a whole, has been previously described mainly in terms of commodities, destinations and mechanisms. Now the research turns to a more detailed view of the trade, communications and transportation networks that supported this trade, starting with the geographical areas of cultural interactions as a whole and then focusing on the Harappan networks; beginning with land based networks and then continuing to riverine and maritime interaction networks, particularly, of course, those of the Gujarat.

4.8.1 Middle Asian Networks

From about the third millennium BC, the geographic areas concerned with trade has been described as the Middle Asian Interaction Sphere. This term, coined by Possehl (Possehl 2002 : 215), encompasses the area ranging from modern Tel Aviv in the west and the Mediterranean to Lothal in the east, Ras al'Janayz in Oman projecting east into the Arabian Sea to the south and as far as the Caspian sea to the north. The main areas of interaction within this expanse, as far as this research is concerned, consists of Mesopotamia, Bahrain, the choke point at the Straits of Hormuz and then across the Arabian Sea to the Harappan cultural expanse.

The evidence for this great geographic intercultural continuum comes from a number of sources. Archaeological discoveries made in Mesopotamia during the early part of the twentieth century combined with the discovery of the Harappan Civilization on the banks of the Indus and artifacts of Harappan manufacture found at numerous Mesopotamian sites indicates intercultural contact. Further work in the post-Second World War era further clarified the northern extremes of this cultural interaction with the discovery of the Turanian Bronze Age culture (Possehl 2002 : 217). Later the importance of Bahrain as a centre for this trade and cultural complex was brought to light by further research (Possehl 2002 : 217).

There is also evidence in the form of conceptual change during this time. The sea going activity of trade was the most important part of the Middle Asian Interaction Sphere and was founded on a revolution in maritime technology, because the pattern of maritime activity changes dramatically during the Third Millennium BC fueled by economic opportunities (Possehl 2002 : 215-216). However, as well as these more obvious developments, the changes also appear to have a basis, with the Harappans at least, in terms of ideology, perhaps seen in the spread intercultural artistic motifs seen in various artifacts (Possehl 2002 : 216-217). Symbology such as fighting snakes, humped bulls, lion-headed birds, huts, date palms, rosettes and simpler designs such as mats, squares, spirals, rain-bow type designs appear throughout the Middle Asian Interaction Sphere (Possehl 2002 : 216). Although some motifs are specific to particular areas within the sphere, for example, the zebu from South Asia, other goods have a broader thematic base, such as at Tepe Yahya in South-Estern Iran and Taut Island near to Bahrain, which gives some indication that there were shared stylistic traits in symbology and perhaps, also in ideology, within this Middle Asian Interaction Sphere (Possehl 2002 : 216).

4.8.2 Harappan Networks

Now some brief observations are made concerning Harappan networks.

Land Based Networks

Some routes within the Harappan extent, were purely land-based, whether by various pack animals (Ratnagar 2004: 236-238) or bullock cart (Ratnagar 2004: 238-242). Major overland trade routes included the Baluchistan/Bolan pass route onto the Iranian plateau and the Khyber Pass into Afghanistan.

More locally, however, as has already been seen, bullock carts formed the primary transportation type for land based networks and examples of this are seen in the modern ethnology of the area and from models made from the Harappan age. These carts, presumably, constituted the adjunct mechanism whereby, larger sites acted as a market areas for smaller surrounding sites as well as a staging area to destinations further afield. This show that some form of central place activity was occurring.

River Networks

Many of the significant Mesopotamian and Harappan cities were accessible via rivers (see 4.6.1 Vessels) such as Mohenjo daro which is near a large and navigable river (Mackay 1935: 175, see 4.6.1 Vessels)

The types of vessel probably consisted of flat bottomed cargo vessels (Greenhill 1976: 67, Figure 22) as well as smaller fishing and transport craft that probably abounded in the riverine environment (see 4.6.1 Vessels).

Maritime Networks

Transportation of heavy, bulky woods of which the Harappans had in great quantities, to Mesopotamia can be considered one of the most favorable argument for maritime trade (Ratnagar 2004: 314, see 4.4.7). Graffiti from Mohenjo daro (Ratnagar 2004: 217) and a clay model from Lothal (Ratnagar 2004:218) indicate a heavier displacement vessels, with a more rounded bottom suitable for sea trade (see 4.6.1 Vessels).

Copper and associated metal alloys for the production of bronze probably came from the Harappans via Oman (Ratnagar 2004: 314), which was most accessible by sea. Some gold that arrived in Mesopotamia arrived from South Asia by ship and there are traces of it at the Harappan site of Shortugai (Ratnagar 2004: 315).

Combined or Integrated Networks

The Harappans engaged in the export and import of a large quantity natural resources and other goods via a well-established system of both overland and maritime routes using pack animals, bullock carts, river boats and maritime vessels (see 2.5.5 Trade).

With this in mind one can envision, using Lothal as a hypothetical example, goods arrived overland by cart, pack animal or small river boat from the hinterlands of Lothal. There, they were sorted and sealed and then sent out by cart again south to the mouth of the Bay of Khambat. From there they were loaded onto larger sea vessels which navigated by keeping the land to starboard as they headed out and then north-east across the gulf of Kutch. The ships continued east in this manner until they reached Sutkagen Dor across the Arabian Sea and then on, perhaps, through the Gulf of Oman and up through the Persian Gulf until they reached Mesopotamia (Kenoyer and Meadow 2001a)

4.9 Importance of Maritime Trade to the Harappans

Lastly, a brief look should be made into Fulford's model concerning the importance of sea-borne trade to maritime cities in order to gauge the importance of maritime trade to the Harappans. As Fulford states in his research, "While primarily concerned with the Roman period, the model can be extended backwards" (Fulford 1987: 58 to 59).

Fulford has investigated the ratio of trade goods, consisting of mainly ceramics, including amphorae table/cookware, that could be positively identified as originating outside the hinterlands of cities. Given the relative scarcity of sites with sufficient archaeological records, the coastal cities of Ostia (near Rome), Carthage (Tunis), Knossos and Berenice (Benghazi) were chosen. Very approximately Fulford found that, taking the time period between 1 AD and 400 AD, Ostia imported about sixty percent of its pottery, Carthage about twenty percent, Knossos about twenty-five percent and Berenice about thirty percent (Fulford 1987: 65).

He concludes from this that these figures indicate a "considerable volume of maritime traffic" (Fulford 1987: 66). In terms of economics alone, Rome was by far the most powerful entity during this time period, and this power seemed to be based not as a producer, but as a consumer. It seemed viable that even, mundane, non-luxury items as ceramics, were cheaper to import by sea than produce locally.

It is now, therefore, evident, that, given a willing and strong consumer and satellite producers, for example, Mesopotamia and the maritime cities of the Harappan Civilisation; high volume sea-borne trade becomes far more probable.

4.10 Summary

Imports included gold from lower peninsula India, for example, Karnataka, silver from Afghanistan and Iran, copper from Rajasthan, lapis lazuli from North-Eastern Afghanistan

and turquoise from Central Asia or Iran. Further proof of intercultural trade are seals from the Persian Gulf and Mesopotamia.

Exports probably included manufactured items such as faience beads. These are decorative tin-plated terracotta beads as well as worked copper, gold, carnelian and pottery.

Water-craft possibly included short-range, reed-raft type boats and various other smaller wooden vessels and larger, shallow draft wooden sailing ships for seagoing voyages. Both reed and wooden vessels appeared to be steered with large stern steering oars. Both had high prows and sterns and flat bottoms or at least shallow draughts. The shape of the fore and aft ends and the flat bottoms of the hulls of both types of vessel suggests that they were primarily, though perhaps not exclusively, beached as low, sharp prows and sterns would easily have become mired prow or stern-first into a muddy river bank. However, this does reopen the question of Lothal as it could mean that the Lothal dock could have indeed been used as such by shallow draft ships, perhaps therefore, is a slight chance that the structure is not simply a fresh water tank after all. However, the main point here is that there is now some geographical criteria that may be considered, that is, shallow beaches rather than deeper water harbour anchorages. In fact, very recent research in the United Kingdom has used a similar idea for finding ports based on boat types to determine favourable geographical criteria. *The Small Ports Project* of the Romney Marsh Research Trust have attempted to identify boat beaching, building and breaking sites by looking for areas where five metre and ten metre contours are one hundred to four hundred metres apart and where five metres above Ordnance Survey datum is the normal water limit (Tyler 2006).

Maritime archaeology research in the past has mainly been concerned with the study of the evolution of vessel technology and underwater exploration, with only a little emphasis placed on the supporting infrastructure of ports, harbours, settlements and landscapes or an attempt to view vessels in relation to wider societal issues (Breene and Lane 2003: 469 to 470). Referring to the East African region, though it could as well apply to any coastal area including the Gujarat, Breene and Lane state that the challenge to archaeologists is to create an "intellectual framework" aimed at providing a more holistic, longer term understanding of coastal archaeology in order to reinvent how the research of coastal areas

may assist in forming cultural histories, as well as, allowing creative ideation regarding contemporary and future society in the wider Indian Ocean (Breene and Lane 2003: 470).

From Sumerian texts Dilmun would seem to be the modern Bahrain and may have served as a link to the Harappan Civilisation which Akkadian texts may refer to as Meluhha (Allchin and Allchin 1982: 188).

Possible port cities such as Lothal with their sheltered locations, access to both inland deltas and, thence, the Arabian Sea, the Gulf of Oman and the Persian Gulf were ideally placed to trade with other Harappan cities, as well as intermediary coastal settlements along the route to either Bahrain or further into the heart of Mesopotamia. This again supports the opinion that the only logical way for the Harappans to use this trade network would be by sea as the overland route to these areas would be tortuous and difficult. Support structures for maritime trade were a well established riverine trade network and land based transportation for transferring commodities into and out of the cities.

As well as the simple carts and given that Lothal perhaps possessed an elaborate dock and considering the possibility of beaching, one could assume that some form of small ship or large boat may have been used for carrying trade goods. Perhaps an idea of the appearance of these early ships can be deduced from a moulded tablet illustrating a boat from Mohenjo daro and a toy boat from Harappa. Both are of the shallow draft variety. The toy boat lacks any detail except for a most generalised shallow hull shape. The mould reveals more detail and appears to depict a boat fashioned from reed with two oars for steering and propulsion at the stern. Both these type of vessels and the bullock carts of the Harappan period seen in many artefacts are still used in the present day for moving goods to and from settlements. These facts further support the mechanism for transporting goods from a beached vessel to a nearby city in the Harappan Period.

Even without other archaeological evidence that confirms the presence of intercultural trade, the fact that the Harappans possessed viable marine technology, made trade and cross-cultural contact between the two civilisations almost certain. Marine technology, that is large, sea going vessels enabled the bulk transfer of commodities, and this efficiency

of transport has been modelled using a multi-agent model (see 4.5.3 Harappan Multi-Agent Transport Model).

4.11 Conclusion

In the period concerned, Mesopotamia was a vast consumer of trade commodities. Although limited in mineral wealth, it used its vast agricultural produce as a ready currency with which to import goods from many places including the Harappan region. Many goods from the Harappans came via Dilmun and the only way for this to happen was by sea. Proof of this trade can be seen from many of the goods found in archaeological record of both cultures, some of which, for example, carnelian, could only have come from Meluhha. Harappan seals and a Harappan weight found in Mesopotamia and the Persian Gulf are further proof of trading connections between the two cultures as are preponderance of Harappan goods in Mesopotamia.

The impact of Harappan trade cannot be underestimated; the Harappan maritime trade network established economic relationships that later connected South, South-East and West Asia to China, in the east and the Mediterranean in the west (Scarre and Fagan 2003: 159). These sea trade routes remain important to this day.

Given a level of uncertainty regarding strong evidence for either the lack or presence of warfare, although it is not yet certain, it could be argued that trade contributed considerably in the further development of the Harappan Civilisation.

The simple trade simulation model designed in this chapter cannot, alone, explain the dynamics of the Harappan trade process and in no way assists in demonstrating the reason for the location of existing sites and new site potentiality in the landscape. Therefore, other techniques must be used, hence the following chapter describes the preliminary stages in the creation and development of the predictive model for site location to be used in this research.

5. Harappan Ports Project Predictive Model: Pre-Construction

This chapter will trace all the steps leading to the selection of a set of attributes that the computer-based predictive model for Harappan port site location model will use.

5.1 Introduction

Included here is a discussion of all possible data sources, for example, direct sources such as geophysical data, as well as those that may be derived from geographical, social or political theory. This is followed by a description of the attributes that are actually selected for use in the model. The section on sociopolitically derived attributes necessitates a brief dialogue concerning political ideologies. Bearing this in mind, it is hoped that this section is, however, largely apolitical and concerned only with selecting the most appropriate tools that may aid in the design of the final model.

Since software is such a integral part of this research, the above will be proceeded by a section where software is reviewed for suitability to the research, including the most vital parts of the software to be used in the predictive model. This will be followed by some explanation of basic concepts in order to convey an understanding of tools, techniques and methodologies that have been used in the construction of the predictive model.

The final part of the chapter will describe the process of putting together the imagery data into the GIS.

5.2 Possible Data Sources

All data sources have been examined within the constraints of mainly time and budgetary limitations. Examples for these constraints include the limited time for available research and collation of data prior to the modelling process, the non-availability of expensive, commercial-only satellite mapping services and also secondary challenges, such as expenses of fieldwork, groundtruthing and administrative difficulties of obtaining

permission for fieldwork in the Gujarat. It should be mentioned that, although fieldwork is always, undoubtedly, valuable in archaeology, this research seeks to create models that will allow the archaeologist to make a decision as to whether further field reconnaissance should be initiated. Therefore the modelling process is, in any case, a pre-fieldwork stage.

5.2.1 Databases

Possehl's Gazetteer

Most of the data for the model has been obtained from two main sources. The first is an electronic copy of the original gazetteer of Harappan sites that Gregory Possehl has added to the Appendices section of his book *Indus Age: The Beginnings* (Possehl 1999: 727-845). The existence of this electronic resource, has been ascertained in conversation with Mr. J. Morris, a curator of the Asian Collection of the British Museum during a preliminary stage of this research concerned with researching Harappan artefacts. However, Mr. Morris has been unable to provide a copy for use in this research. A copy, in the form of a spreadsheet, in terms of provenance, has finally been obtained through Mr. E. Cork, a graduate student of Dr. D. Kennet researching a Masters thesis concerning the Harappan Civilisation at the University of Durham in 2004. The data itself comprises of one hundred and twenty-one columns and two thousand eight hundred and sixty-seven rows of data pertaining to information concerning the Harappan age. Possehl believes that the data contained therein is the most accurate information concerning Harappan sites available (Possehl 1999: 27), though he admits that there is room for improvement (Possehl 1999: 26).

Ancient Ports of the Gujarat

The second main source is data transcribed into a spreadsheet as part of this research from the tabulated results of a more recent paper *Ancient Ports of The Gujarat*, produced by the Space Applications Centre of the Government of India (Thakker et al 2000: 6 to 7). This paper is the work of P.S Thakker, M.H. Raval and A.R. Dasgupta and it appears to be composed for purposes of promoting the use of remote sensing technology in the search for

Harappan age ports in the Gujarat (Thakker et al 2000: 7). The paper mentions a large palaeo-channel, on the banks of which, three sites are situated- Varahi, Benap and Tharad which are assumed to have once been ports because of their location (Thakker et al 2000: 4). The paper goes on to state that the use of remote sensing data has identified many other of these sites in the Gujarat as ports (Thakker et al 2000: 5).

A map of the sites from the paper has been digitised and imported into ArcView and edited to produce a map of possible port sites in the Gujarat (see Figure 5.1 Possible Port Sites in the Gujarat).

Figure 5.1 Possible Port Sites in the Gujarat

Climate

Since the region under investigation is not large, it is unlikely that there will be much local variation in climate and modern climate data has been obtained from the Weatherbase.com web site (Weather Base 2009). This is a commercial company that provides free world weather data procured from reputable sources including the National Climatic Data Center at the National Oceanography and Atmospheric Administration (NOAA) of the Government of the United States of America (National Oceanography and Atmospheric Administration 2009). The records are for the city of Ahmadabad, the capital city of the state of Gujarat, however, this is deemed a little too detailed and general summations of the palaeoclimates of the region are available in other publications, for example, the work of the Allchins (Allchin and Allchin 1982: 28 to 30).

Elevation

The National Intelligence and Mapping Agency (NIMA) of the Government of the United States of America produces place name, longitude and latitude coordinates and elevation data for many parts of the world including the region of this research (National Geospatial-Intelligence Agency 2009). The NIMA data has been downloaded and then searched for place names using the UNIX grep command within a DOS script written in the QBASIC language (Appendix A: nima.bas). The output has been manually cross-checked against latitude and longitude coordinates to ensure that the correct row has been found. This is because there are many similarly named places in India, many of them spelt only slight differently in the English alphabet and often quite geographically close to each other. Also the geographical coordinates of the NIMA data are not perfect and are often an arc minute or two out which makes site identification sometimes even more problematic.

Altitude

Altitude data is also available from the online Global Gazetteer of the website Fallingrain.com (Falling Rain 2009). This data is derived from a variety of online governmental sources including other NIMA data, though it is presented in a much more

accessible format and can be found by simply looking up a web page for a particular place name.

5.2.2 Remote Sensing

Since approximately the 1960s governments and commercial bodies of several nations have been involved in collecting an increasing quantity of imagery of the surface of the earth with a variety of satellite on-board instruments, amongst the earliest are black and white photographs taken by the Agena orbiters of the secret US CORONA program (Kouchoukos 2001: 83). Later instruments on board satellites such as Terra and the Landsat series (Kouchoukos 2001: 83 to 84) have produced imagery of much higher resolutions.

While conducting research in Ireland a researcher has found that aerial photography is useful in archaeology as providing a method for recording the cultural changes wrought on the hidden historic landscape because barely visible observations made from ground level may be more visible from the air where the oblique shadows cast by the angle of the Sun are exaggerated (Barrett 2002: 1). Examples to changes of the historic landscape may include ploughed over archaeological sites that may be identified, mapped and analysed from photographs of crop-marks (Barrett 2002: 1). Surveys from air, may therefore, allow for both empirical data collection and conceptual testing regarding the nature, extent and meaning of settlement patterns by revealing and recording the cultural landscape (Barrett 2002: 25). Analysis of aerial imagery issues a challenge to fully explore the human transitions and transformative processes to the historic landscape (Barrett 2002: 25).

Thus, much of the data that has been attempted to be collected, where available, in various ways, have depended on these developments in remotely accessed data, whether by spacecraft orbiting the earth or developments in aircraft design, which like the internet, has its roots in military objectives of the Cold War.

ESRI Themes

From ESRI, the company that produces ArcView and its larger sibling application ArcInfo, a free world base map has been downloaded (ESRI 2005: ESRI_world_ES_redmap254243103.zip). This has allowed the display of the modern course and location of major rivers, tributaries and water bodies in the geographical area of the Gujarat.

Included in the above are highly contrasting overlays of water bodies and rivers that are helpful as the bright blue contrasts well against a mixed colour backgrounds of the other layers and, therefore, it is useful because possible port sites and harbours are naturally to be located adjacent or nearby rivers, estuaries and coast lines. Taking into account, of course, that many landscape, marine and water features may have inevitably moved somewhat during past millennia.

Also, from the above source, although not immediately useful to finding archaeological sites, additional files for ArcView layers have been added for roads, cities and country boundaries. This additional data could, in theory, prove useful in determining comparisons between modern trade networks and ancient ones in the locality.

Reconstructed Coast of the Gujarat

Although the research into the role of rivers within the Harappan range of the Gujarat, does not rely on each city containing architectural structures associated with ports, given that vessels may have been beached and then goods transshipped overland to their final destination, it is still interesting to note that research into the ancient coastline of the Gujarat may suggest that many port cities may have been far closer to the sea than had previously been considered. It is thought that the sea level, c.4000 BC, was higher than at present (Gaur and Vora 1999: 1). According to Gaur and Vora, due to this fall in sea level, many of the settlement sites of the Harappan Civilisation are now as much as thirty kilometres further in-land. Take Lothal, for instance, it is currently twenty-three kilometres from the present shoreline and twelve metres above average sea level. Besides the disputed "dock" and "anchor" stones, there is evidence of marine salinity in the tank of the

dock area (Gaur and Vora 1999: 2). Also, at Padri, another possible port city, large copper fish hooks have been found (Gaur and Vora 1999: 2). At Kuntasi, "anchor" stones are again found, though their dating is not clear (Gaur and Vora 1999: 3). Dholavira is located in the Rann of Kachna, where the site is located is a dry landscape now, however, it is thought to have been previously submerged under 10m of water. The site still becomes an island during severe monsoons (Gaur and Vora 1999: 3). At Beyt Dwarka conch shells, collumela, and shell bangles have been found (Gaur and Vora 1999: 4, Gaur, Sundaresh and Patankar 2005). Shells have been found at Nageshwar (Gaur and Vora 1999: 4) and excavations at Malvan appears to reveal a Post-Harappan estuarine port (Gaur and Vora 1999: 5).

This Gaur and Vora hypothetical recreation of the of the ancient Gujarat coast line based on the fall of the glaceo-eustatic sea level and the movement of the major Harappan Civilisation rivers over the last 5000 years, although not conclusive, adds an interesting perspective to the importance of the role of rivers in the Harappan trade network. This is because if the sea level remained relatively constant or even lower than is stated in the Gaur and Vora research, then rivers become much more important as trade arteries to the coast. If they were much higher than they are now, then their relative importance diminishes not in the slightest as these cities would then be even more likely to find confirmation in their functional role as ports.

<u>NASA MODIS Rapid Response Project (250 metres)</u>

Prior to the launch of both the Google Earth and NASA World Wind, satellite photographs have been obtained from the NASA MODIS Rapid Response Project at NASA Goddard Space Flight Centre. These have been downloaded via the Rapidfire internet search application (GSFC 2003). This application obtains an archive of images from both Terra and Aqua satellite photographic records between 2001 and 2003. They show wet and dry seasons in false colour as well as a natural colour. The graphic files obtained are colour images in the jpeg lossy format.

Digital Terrain Elevation Data (1000 metres)

Digital Terrain Elevation Data (DTEDs) has also been obtained from the National Geospatial Intelligence Agency, a government agency of the United States of America. Originally developed from Side Aperture Radar tomography (SAR) data, a technique of sending a satellite on multiple passes over a same area and then combining many low resolution images into a single higher resolution image. These images adhere to the US National Imaging and Mapping Agency standard resolution classification levels and are only available at the lowest- level zero. Level zero data provides thirty arc seconds ground coverage, that is, one kilometre in the case of the Gujarat. This data has been downloaded via the NGIA Raster Roam web page application (NGIA 2003a) where users can select the area they wish to obtain, along with the product, that is, resolution level, for example, jpegs or geotiff images at a resolution of one thousand metres per pixel. After user selection, the application will then search for the resultant image and once retrieved from the NGIA archive, it is then ready for download to a user's computer. The geotiff format is favoured for the sake of convenience as this is a single file with georeferencing information written into the header of the file itself. This means that the file can be easily imported into ArcView without further processing.

However, this is very low resolution and not really suitable for precision scientific research, though it does provide a welcome change to the false colour and true colour image layers in that they provide monochrome, shaded relief, high-contrast images with the sun to the north-west. Images such as these help to bring out detail in the landscape. There are higher levels of resolution available to the public for some countries, however, the very best resolutions, that is, levels one to five, or between one hundred metres and one metre are, unfortunately, classified for US military use only (NGIA 2003b). Other sources of free digital elevation data do not any greater utility (Guth 1999: Table 1).

Google Earth and NASA World Wind (1000m to 15m)

The fortuitous circumstance of the completion and release of both Google Earth and the development of World Wind by NASA Ames laboratory, to some extent has assisted the research . Both applications consist of interactive globes, a three dimensional rotating

sphere of the world made up of mosaic imagery from various US government agencies declassified satellite imagery archives.

Both these programs use common data sources. The most significant of these include imagery from the LANDSAT7 satellite, Blue Marble, an interactive globe and SAR imagery from the NASA Shuttle Radar Tomography Mission. The use of LANDSAT imagery in archaeological predictive modelling is not new (Custer et al 1986: 574-575) and has been discussed previously.

Google Earth is a free, though commercial product distributed by the Google internet company. It has more and newer imagery than NASA World Wind from a variety of commercially available data sources, although it does lack some additional useful scientific features found in the other software (Google Earth Comparison 2005). There are also some significant problems with Google Earth in the form of altitude errors (Google Earth 2005).

NASA World Wind is also a free, though unlike Google Earth, it is completely open source. It uses a variety of freely available data sources, many of the same ones as Google Earth. It differs to Google Earth in that it also includes Moderate Resolution Imaging Spectroradiometer data that catalogues fires, floods, dust, smoke, storms and volcanic activity as well as some visual tools such as latitude and longitude grid lines (NASA Ames Research Center 2004).

For both these programs, depending on the particular area, it is possible to obtain up to fifteen metres resolution using imagery from LandSat 7. Both Google Earth and NASA World Wind provide built–in GIS features, such as place-names and also includes the ability to freely zoom in and out from outside the atmosphere to some metres above the surface. As a viewing tool to look at specific target areas of the Gujarat- both programs have proved useful, however, Google Earth seems more suitable overall for the research, mainly because the quality of the available imagery has been found to be of greater utility than the additional advanced features of NASA World Wind.

<u>Topographical Maps (c.21 metres or 1:250,000 Inches)</u>

The University of California at Berkeley has provided the research with topographical maps of the Gujarat. These were created by the United States Army Map Service in 1955 and now reside at the university library (United States Army Map Service: 1955). The staff there have digitised the maps and provided the public with low resolution scans of these paper maps. The low resolution of the scans are unimportant because, if scanned at higher resolutions, the only additional information obtained is the granularity of the underlying paper.

The resolution value has been obtained by using the following calculations-

> Map scale in inches =
> 1:250,000 inches
>
> Convert to mm, given that there are 25.4 mm in 1 inch =
> 25.4:6,350,000.00 mm
>
> Convert to pixels, given that there are 11.81 pixels per inch at 300 dpi (Rossiter and Hengl 2002: 17)
> (25 4 x 11.81):(6,350,000.00 x 11.81) =
> 299.974:74,993,500.00 pixels
>
> So 1 pixel is 74,993,500.00 / 299.974 =
> 1:250,000 pixels
>
> Convert pixels to mm
> 250,000.00 / 11.81 =
> 21,168.501 mm
>
> Convert to metres
> 21,168.501 / 1000 =
> 21.16850 m

Therefore, the digitised paper map has a resolution of roughly 21 m / pixel

Note, the formulae and methodology for the above has been obtained from the lecture notes of Rossiter, D.G. of the International Institute for Geo-information Science & Earth Observation at Enschede in the Netherlands (Rossiter and Hengl. 2002).

The maps show the various environmental features, as well as man-made features, c.1950s. Due to the relative complication of incorporating these slightly distorted images into ArcView, they have simply been used as a visual reference source.

<u>Aerial Photography (500 feet and above)</u>

An exhaustive investigation into the possibility of finding commercial, government or military sourced aerial photography of the Gujarat region has been conducted in the hope of finding sources of aerial photography either from colonial or post-colonial India. The following institutions have been contacted-

The School of Oriental and African Studies (SOAS) Library in London
The British Library in London
The Bodleian Library of Commonwealth and African Studies at
Rhodes House in Oxford
The Cambridge University Library Photography Office
The Cambridge University Unit for Landscape Modelling (Aerial Photography)
Royal Geographical Society, Picture Library in London
British Empire & Commonwealth Museum in Bristol

It is unfortunate, however, that none of these institutions have any aerial photography for the area of study in the Gujarat. The last source had aerial photographs of India between the 1940s and 1950s, though none of the Gujarat.

Another method of obtaining high resolution imagery from aerial photography, could be the use of radio control aircraft (Harvey 2005) or kites. This avenue has been thoroughly

investigated as Kite Aerial Photography (KAP) has been widely used for many years in archaeology (Aber and Aber 2004: 1). To this end a kite has been acquired, a picavet rig for holding a camera in a constant horizontal position and a field-of-view calculator computer program developed to aid in ascertaining ground coverage (Appendices: fovcalc.bas). However, due to budgetary and time limitations as well as bureaucratic problems the system designed has not been deployed in this current research.

The following is a brief summary of the availability of surface imagery, described in detail above-

Image Source	Resolution (m/pixel)
NASA MODIS	250,000
NGIA DTEDs	1000
Google Earth	Between 15 and 1000
NASA World Wind	As above, but less data than google
Topographical Maps	21
Aerial Photography	0 (Not available)

The search for viable remote sensing data at high resolution has resulted in a serious short-fall and this may, on reflection, seem disappointing. However, this situation now forces the research to freely and more fully explore other avenues of research. Due to less reliance on imagery based graphical data sources, there is an increased necessity to explore the opportunities that predictive models may offer for using other sources of data.

5.2.3 Human Geography, Social and Political Theory

Well known geographical models such as Christaller’s Central Place theory, derivatives thereof, as well as others that will shortly be described all require substantial data input to be of any use. While it is the case that data, such as location of agricultural areas and central markets are important, the models also assume gross simplifications in order to describe certain processes, such as, for example, human habitation and movement. Given

the limited resources available, particularly that of time, it has been decided that only a few selected theories will be put to use. The data that they require as input will be derived from the model's graphical analysis functionality which can discern major elements describing site dispersion. This function will be described in greater detail later.

5.2.4 Libraries

A comprehensive search has been conducted that includes the book collections and archives of the libraries of the universities of Newcastle, York, Durham, the School of Oriental and African Studies, the Institute of Archaeology, the British Library and the Foyles book shop in the United Kingdom. The libraries of Simon Fraser University and the University of British Columbia in Canada have also been used extensively.

5.2.5 On-line

As well as the online archive JSTOR, the Harappan Research Project (HARP), Google Scholar and other academic on-line resources, well known to most scientists, as well as on-line book shops such as Abe Books, Amazon and Oxbow, a special automated search script has been developed to search using the Google search engine. This program (Appendix A: superget.bas) has allowed the search of each of forty-five possible ports sites in the Gujarat using the following search terms-

palaeometeorology
mesometeorology
neometeorology
climate
faq
altitude
sea level
beach gradient
coastal gradient

This program, which runs for less than one minute, has saved many hours of manual searching, though the web page results of this search still needed to be read manually.

Other automated Google searches, using the above program, have also been conducted for the following terms-

Gujarat coastal gradient
archaeology site report
Gujarat marine navigation maps
world meteorology

5.2.6 Other

The *Small Ports Project* of the Romney Marsh Research Trust mentioned earlier have attempted to locate boat beaching, building and breaking sites by searching for locations where 5 metre and 10 metre contours are 100 to 400 metres apart and where 5 metres above Ordnance Survey datum is the normal water limit. In theory similar environmental criteria can be used to locate beaching sites in the Gujarat (Tyler 2006).

5.3 Possible Attributes

There are many attributes used in predictive modelling, previously discussed in various case studies, that are traditionally used in site location models. These are generally physical and environmental features based criteria that are commonly used in GIS software, such as, hill-shade or aspect. These type of criteria are fully described in other works (see van Leusen and Kamermans 2005, Westcott and Brandon 2000). Here, however, various common models from human geography, as well as other less commonly used physical features and archaeological subject areas, will now be briefly considered. Note, that for the sake of brevity and so as not to stray solely into the realms of other disciplines, only brief descriptions of the various specialised models will be offered. This

is particularly the case for the geographical models that follow. A basic text, *Human Geography: Theories and Their Applications* (Bradford and Kent 1986), available to most first year under-graduate students of geography in the United Kingdoms has been used in the interest of simplicity and conciseness.

5.3.1 Location

Given that the main reason for developing a predictive model in the first place is to locate new sites, theories that attempt to explain site location are rather useful to this research. In addition to assist in locating sites by using these theories, it may also be possible to analyse and form conclusions as to the reasons governing the distribution of Harappan settlements in the landscape.

<u>Conforms to Christaller's Central Place Theory</u>

Central place theory is a very commonly used model in geography, it has been devised by Walter Christaller, who bases his theories on the earlier work of fellow Germans Johann Heinrich von Thunen and Alfred Weber. It is an explanation of the relative locations and size of settlements (central-places) and their hinterlands. The theory makes the following assumptions-

A flat surface with no boundaries

Equal ease of transport in all directions.

Even population density.

Settlements provide goods, services and administration.

Consumers, all of equal income and demands, will visit the nearest settlement that provides them with one of the above.

> Suppliers try to obtain the largest market of consumers by locating themselves as far from one an other as possible, though not so far as to be out of the reach of a possible consumer.
>
> There are higher order settlements, that in addition to the functions offered by lower order settlements, provide some extra functions.

Christaller assumes that settlements are surrounded by circular market areas and, so that no consumers are unserved, these circular zones overlap forming a of hexagonal pattern. Further, various principles are defined- marketing, traffic and administrative principles are represented topologically on a plane by "k" values-

> k=3, the marketing principle, where one lower order centre has the choice of obtaining goods and services from three surrounding higher order centres.
>
> k=4, the transport principle, where one higher order centre services three lower order centres as well as itself.
>
> K=7, the administrative principal, where administrative services are provided by one higher order settlement to itself and six surrounding lower order settlements.

These are the basic principles described by Christaller and used in his analysis of settlement patterns in Southern Germany (Bradford and Kent 1986: 6 to12).

This theory has been considered in Harappan archaeology, at a somewhat basic level, as it has been seen previously in the research of Lamberg-Karlovsky (Lamberg-Karlovsky 1972: 222). Also its use in archaeology in general is not a new concept as can be seen from the work of Johnson in Mesopotamia during the early 1970s where CPT has been used to survey graphic site placement results and reveals the difficulty of applying a geographical model to a real site (Johnson 1972: 181).

<u>Conforms to von Thunnen's Economic or Locational Rent Model</u>

Johann Heinrich von Thunnen bases much or his research on real-world data gathered from his own agricultural estate. Again certain assumptions are made to simplify the model.

> The simulated world only has one city located in the centre of an unvarying and equally fertile agricultural plain.
>
> This city is the only market and all the prices are the same.
>
> All farmers are assumed to be purely market driven entities.
>
> There is only one form of transport.
>
> Greater distances always equate to higher corresponding costs for the provision of transportation.

In brief, this theory concerns the difference between total revenue and production, and transportation costs for a particular crop. This is described as economic locational rent. There are two forms of the model, described as follows-

> The first, in essence, states that, if all accountable factors are equal, that is, the same crop type and volume, then the farmer with the least distance to travel will attain the highest profit margin.
>
> In the second instance, only crops that produce the highest locational rent will grown, after taking into differing transport costs based on bulk of crops and the distance from market.

(Bradford and Kent 1986: 28 to 31).

Conforms to Weber's Industrial Location Model

Alfred Weber explains the location of industrial activity in terms of transport costs, labour costs and agglomeration economies, that is, the savings made by individual manufacturing centres by basing their locations near to each other.

The assumptions made here are that-

> An uneven distribution of raw materials, fuel and water on a plain with uniform costs and a uniform transport network.
>
> Fixed markets and labour points providing unlimited resources.
>
> All entrepreneurs try to minimise the costs of production in an environment of perfect competition with no monopolies.

On this basis Weber analyses locations with the least transport expenditure and the reasons why production may move away from these locations (Bradford and Kent 1986: 42-43).

The relevancy to the study here are the questions Weber's theories pose. Why are not all Harappan Civilisation cities in the Gujarat situated near to rivers, given their critical role in transportation of goods? Perhaps one reason to be considered should be that the least-transport-cost may be offset against the constant risks of flooding.

Conforms to Burgess's Model of Urban Areas

E.W. Burgess, an American sociologist at the University of Chicago has sought to explain the internal structures of cities. He bases this particular urban model on the city of Chicago. The model attempts to offer a broad description of the different functional areas of a city. Burgess's theories are somewhat different from those mentioned earlier in that the research is based on studies of plant ecological systems, hence, the use of analogous terms such as "invasion of natural areas" by competing groups, "competition" between

invading groups and invaded groups, "dominance" by an invading group leading to "succession" in an area.

The model assumes-

A variation of culture and societal strata.

That the city has a commercial-industrial base.

There is private ownership and competition for space.

There is an expanding city and population.

The city is uniform in terms of availability of transport and desirability of all areas.

The city centre is the main employment district, thus space is limited, competed for and valuable and the opposite is assumed for periphery areas.

That there is no concentration of heavy industry or imprinted historic land-use patterns in any area.

This model divides a city into different zones- Zone 1 or the Central Business District (CBD) is the main hub of the city and is the retail, financial, commercial and administrative heart. Zone 2 is a transitionary area invaded by newcomers in light industry, business and sub-divided housing. Zone 3 is primarily a residential area for industrial workers and Zone 4 a high-class residential area. Zone 5 is outside the city limits in a suburban or satellite commuter zone (Bradford and Kent 1986: 70 to 72).

These zones, with some modification, map well, at least at a conceptual level, to the highly organised, structured and discrete layout of the Harappan cities.

Conforms to Hoyt's Sector Theory

Hoyt also shares the assumptions of Burgess except for uniformity in the availability of transport. It is based on the study of one hundred and thirty-nine cities in the United States of America. It has become known as the sector model for its sectional representation of zonal occupation, though it also demonstrates that low and high rent sectors personify a polarity of mutual repulsion and that high-rent areas tend to relate to the fastest routes to and from the Central Business District (Bradford and Kent 1986: 72-73).

Conforms to Mann's Concentric Zone Model

In the United Kingdom, Mann seeks to unify both the Burgess and Hoyt models by incorporating one centre with commuting from outside of the city. Here, the Best residential zones are at the opposite edges of the city away from the industrial zone (Bradford and Kent 1986: 76).

Conforms to Harris and Ullman's Multiple Nuclei Model

Harris and Ullman have also modified the Burgess-Hoyt models by stating that land-use patterns within a city are not central, but spread around multiple discrete nuclei. This is because-

> Different activities require specific facilities, for example, ports require both waterfronts and storage facilities.
>
> Grouping of similar functions or Weber's agglomeration economies and separation of dissimilar zones, for example, Hoyt's repulsion theory for heavy industry and high-class residential areas.
>
> Different industries can not afford the same rents, for example, manufactories will not be able to pay the same rents as higher income generating service industries.

(Bradford and Kent 1986: 76-77).

Conforms to Population Density Model

This simple theory states that there is an exponential decline in population density as the distance from the city increases (Bradford and Kent 1986: 77).

Conforms to Land Value Model

In a similar way to the aforementioned population density, here land value is said to decline with distance from the city centre (Bradford and Kent 1986: 79).

5.3.2 Movement

The movement or migration of people is an important factor relating to the development of settlements, particularly in terms of size and density and is a good indicator of overall success. The reasons for this are examined in the hope that some of these theories may be usefully applied to the predictive model.

Conforms to Ravenstein's, Warntz's and Reilly et al Gravity Model

Rather than how Burgess grafts ecological process models into the terminology of urban geography, instead Newtonian physics, specifically the theory of gravity has been used to explain the movement between areas over time.

A non-mathematical way of explaining this theory clearly is that as two objects draw closer to one another, there is also an increase in their mutual attraction. Thus, in terms of movement, the further apart two settlements are; the less migration between them is likely to occur. It should also be seen that as each town grows, the distance between them shrinks, thus the migration between them correspondingly increases (Bradford and Kent 1986: 114-115).

Although not as yet applied to the Harappan historical and cultural milieu, the gravity model has been used before in archaeology by Grzymski in 1986 with his research into Nubian archaeology (Grzymski 2004: 10).

Conforms to Hägerstrand's Diffusion Model

Torsten Hägerstrand, a Swedish geographer seeks to explain the diffusion of people and ideas or innovation over time. Rather than ecology or physics, mathematical games theory is used incorporating Monte-Carlo techniques. That is, an element of random chance is added, originally based on the idea of roulette wheels in Monte Carlo casinos. Again, as in the previous models, it is thought that the transmission of ideas and people decreases over distance (Bradford and Kent 1986: 128-131).

Conforms to Morril's Ghetto Expansion Model

Morrill's ghetto expansion model seeks to explain the movement of people over time.

This model assumes-

A five percent population increase every two years.

Migrants move based on information about opportunities that decreases over distance, thus people are more likely to make short distance moves.

Actual movements of individuals is randomly determined.

The model, fairly accurately determines movement in the city of Seattle in the United States of America with respect to its black population from 1940 to 1960. There are, however, strong racial factors that determine the model such as desirability of whites to locate away from black ghettos and the decrease of rent in white areas near to the encroaching ghetto (Bradford and Kent 1986: 136-138).

Without specific ethnically-based data, it is difficult to see how this model can be used currently in an analysis of Harappan cities.

Conforms to Berry's Diffusion of Television Stations Model

This model by Berry seeks to explain the diffusion of television stations and television sets in America. Simply put, higher population density equates to more television stations and higher income areas also have more television sets.

This Hägerstrandal type diffusion can also be seen in the relationship to trams in America and building societies in the United Kingdom (Bradford and Kent 1986: 138-140).

Its relevancy for Harappan cities should be clear, higher income groups can afford more luxuries, for instance, better housing and luxury items. Areas with greater population density also have access to more services.

5.3.3 Population Growth

Here demographics is examined and various population growth models analysed for suitability of inclusion in this research.

Conforms to Malthus's Population Change Model

Thomas Robert Malthus has proposed ideas that aim to interpolate the variance in population in relation to resources. The basic theory is that populations will grow at a geometric rate in the absence of negative growth factors. For example, over twenty-five years the population can double. In this same period, production from the land can only grow, however, at an arithmetic rate. It should be noted, however, that although the relationship of population and resources leading to what may be termed "over", "under" and "optimum" populations are difficult to quantify in an economy that is not purely agrarian. Also, other factors may have an input such as technological development and societal attitudes (Bradford and Kent 1986: 144-49).

This theory is possibly applicable to explain the declining years of the Harappans, though it is difficult to see how this theory could be applied with effective utility in the proposed predictive model or where, precisely the data could be directly sourced.

<u>Conforms to Boserup's Theory</u>

Here, Boserup has modified the Malthusian theory by stating that an increase in population can lead to a corresponding change in agricultural practice in order to increase production efficacy (Bradford and Kent 1986: 149).

Again, it is difficult to see how to apply this theory to the Harappans as this theory can be more usefully applied to mainly pre-industrial and largely agrarian societies.

<u>Conforms to Durkheim's Theory</u>

Durkheim in France takes this further and states that population increase is indeed vital for greater productivity through division of labour (Bradford and Kent 1986: 150).

In terms of non-agrarian factors such as clearly delineated locations of industry such as bead-making, this theory could be applied favourably to Harappan cities.

<u>Conforms to Limits to Growth Model</u>

Here certain factors are said to limit potential growth of a settlement. These are physical necessities, such as natural resources and social necessities, such as social stability and peace. This model has been developed to predict the ultimate limits to growth of the planet and predicts system collapse through resource limits well before 2100 AD if a "state of equilibrium" is not reached (Bradford and Kent 1986: 150).

This rather macro-scale model can be of some relevance in explaining decline indicators in the latter years of Harappan society.

Conforms to Demographic Transition Model

This theory seeks to explain the relationships between birth and death rates. The premise here is that, over time, the birth-rate and death-rate decline. The model predicts five stages of demographic transition-

Stage one- high fertility and high mortality.

Stage two- high fertility and declining mortality.

Stage three- declining fertility and declining mortality.

Stage four- low fertility and low mortality.

Stage five- fertility drops below mortality resulting in a decreasing population.

The problem with this model is that it is largely Euro-centric (Bradford and Kent 1986: 152), further, this model, again seems difficult to apply to the Harappan scenario without the availability of accurate population data.

5.3.4 Economic Growth

While still on the subject of growth, an examination ids now made of the applicability of economic growth models.

Conforms to Sector Model

This model is developed from the previous work of economists such as Clark and Fisher in the United Kingdom and is linked to Lösch and Hoover's research. It aims to explain variance in the proportion of the workforce employed in different economic activities.

The sector model consists of three employment types-

Primary employment that includes agriculture, hunting, fishing and mining.

Secondary employment including manufacturing.

Tertiary employment including commerce, transport and various services.

It is thought that, over time, primary and secondary employment decreases, whereas tertiary employment increases. The basic reasoning is that although incomes may increase, demand for food is inelastic, while demand for other items such as luxury goods and services increases (Bradford and Kent 1986: 158 to 159).

Again, it seems difficult to apply this theory to Harappan society because although domestic luxury goods existed, it seemed to be a culture whose mercantile economy or tertiary employment group appeared to be mainly involved in their export. This says little of what the increasingly wealthy Harappan society considered to be luxury goods and services, though, perhaps items such as the "dancing-girl" statuette gives a minor indication. One must also consider less overt hoarded wealth because the act of hoarding indicates a desire to accumulate wealth covertly and, as a purely secular act, this is a more objective indicator of wealth (Rissman 1988: 209); hoards have been discovered in various locations such as, for example, Mohenjo daro (Rissman 1988: 216).

One could say, at the least, however, that the tertiary employment sector is, in part, responsible for the wealth of Harappan society in its mature period with many of its cities acting as administrative, as well as transshipping centres. Thus, the progression through the various employment stages can be demonstrated.

<u>Conforms to the Development Stage Model</u>

The roots of this model also lie in the derivation of the works of Clark, Fisher, Lösch and Hoover. Here, instead of employment type, the focus shifts to economy type. The development of regions are said to progress through stages-

Self-sufficient economy including hunting and gathering and sedentary cultivation, leading to the establishment of farms and villages.

Specialised production in primary activities and interregional trade with transport improvement leading to small market towns.

Secondary industries such as manufacturing, exports may lead to the development of ports.

Diversified industrialisation and rising incomes, for example timber processed into planks and the planks used to build marine vessels.

Specialisation in particular tertiary activities, for example, specialised personnel such as customs officers.

(Bradford and Kent 1986: 160-161).

Certain aspects of this model could be applied to the Harappan scenario such as the history of continuous development from sites such as Mehrgarh to later, more sophisticated sites involved in trading such as Lothal.

<u>Conforms to Rostow's Development-stage Model</u>

Rostow proposes a modification of the above theory. He examines data from fifteen countries over a great period of time and suggests that all countries undergo a similar route of development. These are described as-

Stage one- traditional society

Stage two- preconditions for take-off.

Stage three- take-off.

Stage four- take-off to sustained growth.

Stage five- drive to maturity.

Stage six- high mass-consumption.

(Bradford and Kent 1986: 161).

Stages one to five seem to be analogous to Harappan development and stage six somewhat describes the human factors relating to possible later decline due to overconsumption of resources.

<u>Conforms to Myrdal, Hirschman and Friedmann's Core-Periphery Model (Theory of Polarised Growth)</u>

This is largely a development by numerous geographers of the work of the economists, the Swedish Gunnar Myrdal and American Albert Hirschman as well as John Friedmann a regional planner. Here it is thought that there are growing interdependence of regions within a country and it aims to explain regional differences in development in terms of space. Areas are classed as follows-

The core region is the main market serving the entire nation.

Upward transitional areas are located relative to the core. They are successful possibly due to intense use of resources. They feature increased immigration, agricultural production and investment.

Downward transitional areas with poor access to natural resources are stagnant and possibly unchanging technologically, leading to low productivity and low life expectancy.

Resource frontiers, as the name suggests, are areas where new resources are discovered and exploited. Similar to the core region, these areas are important in stimulating regional development.

Various processes drive the development or decline of these areas, for example the core may experience concentration of resources called "backwash" by Myrdal or "polarization" by Hirschman. "Virtuous circles" or upward spirals in the core can set off corresponding "vicious circles" or downward spirals in the periphery. Growth in the periphery is explained by Hirschman as a "trickle down" and by Myrdal as a "spread" effect. Growth of the core increases demand for food and resources from the periphery. In return the core supplies various goods and services, for examples tools, to enable the periphery to meet this increasing demand (Bradford and Kent 1986: 167-172).

The above is a very simple explanation of what is a rather complicated model. It would rather stretch credulity to try to apply this model to the Harappan Civilisation, given the complex nature of the model. It does, however, perhaps, explain the geographical relationship of between some of the sites during the Harappan Period, given the difference in site function. For example, the non-Harappan site Mehrgahr that survived amidst Harappan sites well into the Harappan Period. Perhaps this is example of a periphery agricultural site.

5.3.5 Transport Networks

It may be possible to apply geographical theories pertaining to the development of transport networks to the model. Here the various theories attempt to describe and interpret the location and development or transport routes and networks. Although many are concerned with the formation of more modern networks such as those of motorways, canals and railways, it is hoped that these networks, speed and technology aside, will cast some relief on more primitive modes.

Conforms to Haggett's Deviation Model

This theory tries to interpret the ways in which routes often deviate from the straight line or shortest path solution. Haggett develops a hypothesis for these deviations using the work of Wellington and Lösch and call these, respectively, positive and negative deviations-

> Positive deviation is where a route is diverted from its chosen destination for some type of gain. An example of this are the railway routes of the nineteenth century where routes often incorporated the smallest settlements in an attempt to gain extra passengers and custom.
>
> Negative deviation is where a route diverges from its goal in order to avoid an obstacle. Such routes could include hostile mountainous areas or high value land, for example, where some valued structure already exists.

(Bradford and Kent 1986: 188-190).

Positive deviations may be an added explanation as to why it is thought that the Harappans chose a mostly coastal route. As well as easing navigation, perhaps it was to also engage in coastal trade on route to the ultimate destination of Mesopotamia.

Negative deviations could have included mountains to the north-west or avoidance of the, possibly hostile, Elamites leading the Harappans to favour sea routes for bulk trade. It appears, therefore, that the theory of Haggett fits well with Harappan trade with Mesopotamia and may also explain the coastal route.

Conforms to Bunge's Six Alternative Solutions to Connecting Five Centres Model

Bunge's ideas are more topological in nature and suggest that there are six alternative solutions of how to build a route to connect five centres-

> First, simply the shortest route between all five points.

Second, the route starts and finishes at the same point taking the shortest distance between all the other points.

Third, the route could instead use one point as its home base and then travel from this point to one of the other points, returning again to the home point before travelling to another distance point.

Forth, all points could be connected to all other points.

Fifth, the shortest path between all points is used.

Sixth, a loop network with that including all points.

(Bradford and Kent 1986: 96-97).

In the case of the Harappan culture it is difficult to envision how to apply a particular routing solution. It is possible that all or some of the solutions are valid, but the question of which ones are more favoured is more difficult to ascertain. One might make certain assumptions, however. One such crude assumption is that, solution one seems the most likely model for maritime trade. Also, perhaps, any trading route that is going to minimise routes that deviate from any settlement, except, of course, hostile enemy territory is a more favourable route. However, other than stating that solution one is possible in relation to maritime trade, using additional aspects of this hypothesis is problematic.

<u>Conforms to Kansky's Railway Topology Model</u>

The aim of this model is to predict the form of the Sicilian railway network. Inclusion of settlement on the route is based on-

Approximate income of settlements.

Size of settlements.

Distance of settlements from existing networks.

The results of Kansky's work, while not perfect, display some accuracy (Bradford and Kent 1986: 99-100).

Although, it is possible to map certain aspects of Kansky's ideas on to Harappan routes, without an in-depth and time-consuming look at his research methodologies, it is not possible to see any benefits of pursuing lines of enquiry pertaining to this hypothesis. It could be said, however, from Kansky's findings, that the wealth of a settlement strongly correlates to its inclusion on any particular network.

<u>Conforms to Taafe, Morrill and Gould's Evolutionary Model</u>

In geography, this is a well-known example of the evolutionary approach to transport networks. The basic premise, as set out by Taffe, Morrill and Gould in their study of the formation and modification of transport networks in developing countries, namely Ghana and Nigeria, is that there are six stages of transport network evolution-

A scattering of small ports along the coast with small fishing craft and occasional trade vessels.

There is communication between ports and the hinterlands are extremely limited in range.

Market areas expand for some ports, lowering the cost of transportation from the hinterlands and travel and feeder routes concentrate on interior centres and the major ports.

Hinterlands of the major ports expand, while those of smaller ports contract correspondingly.

Main routes to interior centres develop nodal points with their own feeders.

Some nodes capture the hinterlands of smaller nodes and feeders start to connect.

Lateral links develop between both ports and interior centres until all points are connected.

Routes have reached full development and now main or high use routes emerge.

Inland links develop for a number of reasons. It is partially to connect coastal administrative centres with inland centres as well as to exploit the natural wealth of inland sites, for example, due to rich agricultural areas or areas or high mineral wealth. There are a few problems with the hypothesis. One such problem is the size of the sample group used in the study, that is, just two African states. It is also difficult to separate the stages as one stage, almost organically, merges into the next state, therefore, these stage delineations are somewhat artificial and contrived. Also, the hypothesis does not explain the mechanism for the increased complexity of this topological system over time. Gould does suggest, however, that in contrast to other transport network models discussed here, because these countries are former colonies, their routes have developed more as exploratory forays. Route development stems from either speculation new routes or expansion of existing routes. (Bradford and Kent 1986: 99-102).

How does this theory assist in Harappan research? In some ways, it could be said that any culture which has the material wealth enough to invest in speculative trade or even military ventures would follow a similar pattern in the development of its transport infrastructure. It is known that the Harappans were materially wealthy, that they also were commercially active. Simply from this point of view, speculation must have formed a part in route-planning. To what extent this approach applied to the Harappans is, however, is open to debate and difficult to ascertain.

5.3.6 Sociopolitical Theory

One of the novel aspects of this research is to expand the concepts used in predictive modelling for site location by including factors other than purely environmental data.

Though part of this can be accomplished by use of certain aspects of geographical theories, theories from other subjects should also be examined for their potential use. Therefore, attention is now turned to the various schools of thought available from the school of social and political theory.

Conforms to Marxist Theory of Class Formation

For many reasons social theory is important in archaeology. For example, take the Marxist idea of the development of society. If one puts aside later communist rhetoric and relativism that can colour objectivity in any school of thought, there are some ideas worth considering. Most obviously, the Marxist theory of historical materialism where society is driven through the dialectical process to change due to external pressures such as, for example, economic need. This emphasis on external forces can also be seen in the decline of Harappan society, due largely to a variety of environmental factors as well as other reasons. And the classic philosophical theory of the dialectic process itself can, of course, be seen as a mechanism for any trial and error development process, such as, for example, the technological evolution of stone tools.

Another case to consider is the opposition of the terms "stone", "bronze" and "iron age" and its proposed replacement with "pre-clan", "gentile" and "class formations" by Soviet archaeologist P.P. Efimenko (McGuire 1992: 58). Its addition to archaeological thought might be possible as it usefully shifts the focus of archaeology from its view of societal development driven mostly by technology into a cultural development also built from a basis of social change. Unfortunately Efimenko proposes it as a total replacement of the earlier definitions of development and it is here that problems arise by trying to fit political ideology with the pursuit of scientific knowledge.

Therefore, in order for social theory as a whole to work in the archaeologist's favour a strategy of eclecticism is preferred where one can pick and chose between the various social theories rather than being mired in one particular school of thought that may very well become obsolete, or becoming distracted by the huge body of work that is social theory (Schiffer 2000: 3).

Conforms to Evidence of Sophisticated and Powerful Leadership

Powerful leaders are defined by their ability to control non-kin labour (Arnold 2000: 21). They are able, for instance, to instigate major projects such as the building of a communal structure such as a store house or grain silo. Arnold's hypothesis (Arnold 2000: 18), simplified, is that there are three different forms of society-

> Small scale, where there are, for example, leadership structure and kin elders who command house-hold or kin labour.
>
> Intermediate hierarchical, where elders and chiefs both hold rights to labour, with chiefs commanding a large proportion of non-kin labour.
>
> Complex hierarchical, where elders, chiefs, kings and bureaucratic apparatus all hold rights to labour.

(Schiffer 2000: page?)

This concept of leadership is directly relevant to any study of the Harappan culture. Though there is still a debate as to the evidence for kingship, it is obvious that building such a well structured and governed society such as that of the Harappans required some form of leadership structure. It does not matters whether this is accomplished by a committee or one leader, what matters is that it can be said for certain that there was a powerful leadership structure present and that this indicates societal development of the third kind, that is, a complex and hierarchical one.

5.3.7 Physical and Archaeological

Now that the novel aspects of utilisation and relevance of various geographical and sociopolitical attributes have been discussed, attention is now focused on some more esoteric and less used physical and archaeological attributes. Therefore, as well as the more mundane attributes obtained from numerous sources such as the analysis of remote

sensing data for locations of palaeohydrological features or the study of archaeological data to determine possible shared artefact typology, one might also consider the following.

Archaeoastronomy/Cultural Astronomy

Sub-branches of archaeology such as archaeoastronomy and ethnoastronomy (Baity et al 1973: 389) may one day further illuminate the Harappan culture. Although, it is assumed that astronomy as a science originated from either Mesopotamia (Neugebauer 1975: 2) or Egypt (Lewis 1862: 256) at around 300 to 700 BC, it does not necessarily obviate astronomy in other Old World cultures such as the Harappans. One must remember old ideas regarding astronomy have, in the past, been dismissed at first and later accepted as was the case of General Charles Vallancey who claimed of the existence of astronomical devices at Newgrange in Ireland (Brennan 1983: 24).

If the Harappans were, in fact, culturally cohesive in terms of science, art and religion, then it could be argued that seeing the same night sky was important over the whole extent of the Harappan culture. It may be assumed that astronomy may have played some part in the life of the Harappans, if only, for example, the use of the night sky as a calendar for agricultural purposes. If it is proved by future research that the Harappans did, in fact, use astronomy to any extent whatsoever, it will dramatically put back the age of astronomy in India as it is currently thought to have begun in the Vedic period (Shukla 1987: 9). It is prudent to note that astronomy is not new, with the earliest stages of Stone Henge in the United Kingdom being older than 2000 BC (Krupp 1978: 89). The science of archaeoastronomy seems to be developing rapidly, therefore, it is not outside the bounds of possibility that some new astronomical aspect relating to the Harappans will be discovered as it has been the case for the Australian aborigines (Ruggles 1993: 136). Also, almost every culture researched seems to have had some astronomical science, from the Old World culture of China (Sivin 1986: 56) to the New World culture of Aztecs (Aveni 1980: 33) or the Anasazi of Chaco Canyon (Malville and Putnam 1989: 28).

Thus, the following attributes could be significant-

The visibility of the Northern or Southern Hemisphere night sky.

> That the sky is fully or visible without physical obstacles, not including climactic obstructions.
>
> That the sky is partially visible, offset by the beneficial aspects such as favourable valley micro-ecologies, shade and access to water (Badenhorst 2007) from mountain springs and glaciers.

To illustrate the possibilities, a screen shot taken using the Redshift computer program is included overleaf. It shows the sky, horizon and constellations during the mature Harappan period at a point within the centre of the area of study.

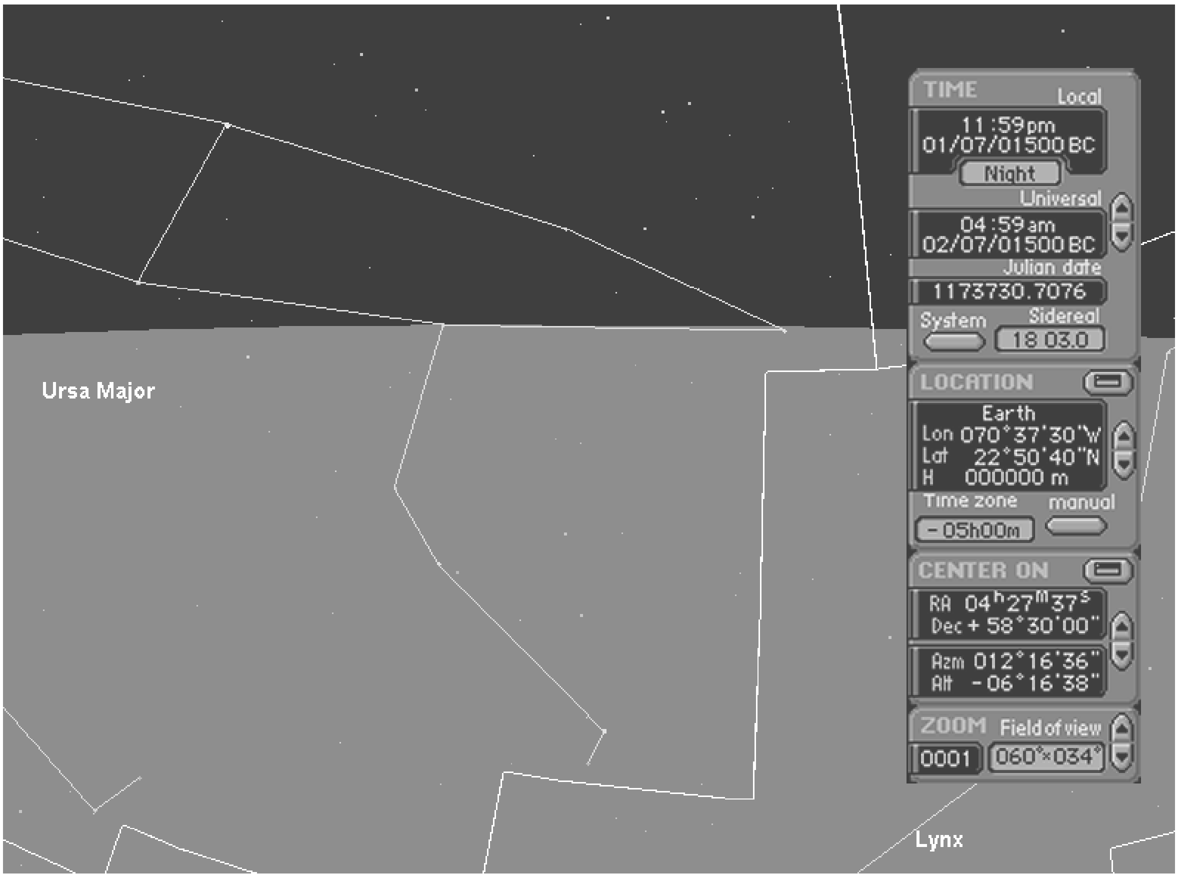


Figure 5.2 Night Sky, Kuntasi, 2500 BC

Potable Water Sources

Distance and depth to most easily accessible and most available potable water source is a useful attribute. Although this attribute may appear overqualified, there is no reason to believe that the nearest source of drinkable water is always the source used by the culture in question. This is because there is also a question of accessibility; a gaping chasm or a ten percent gradient is less appealing than a walk of an extra kilometre.

Geoarchaeology

From the field of geoarcaheology, one might consider basic soil micromorphology, such as-

> The presence of primary, secondary or tertiary deposits indicated possible periods and types of activity.
>
> Soil type, texture and PH level give an indication of possible ceramic use or crop types.

Zooarchaeology

This research area, and attributable data thereof, could prove particularly useful in studies of Harappan Civilisation when the following is considered.

The Fertile Crescent is the area from the Mediterranean coast in the west, Eastern Turkey in the north and the Zagros Mountains in the east. Similar crops and domestic animals spread from this region as far as Ireland in the west to the Harappan region in the east (Reitz and Wing 1999: 280).

The Harappan region is then the most easterly extension of this crescent, where agriculture is said to have first emerged 8-10,000 years ago. These dates correspond with what is known about the spread of agriculture from the Bolan pass and the founding of the agricultural village of Mehrgarh which has been discussed previously. Thus, the age of the

Harappan region and the Harappan culture may also be apparent from studies of zooarchaeological remains.

As well as confirming the presence of sites with a similar use of livestock, zooarchaeology can also indicate human economic development (Reitz and Wing 1999: 28) as well as the state of the local environment (Reitz and Wing 1999: 29). Agriculture leads to the ability to control food production, both in terms of animals and plants, within a chosen area and drastically reduces the need for hunting and gathering. This is said to be fundamental to the establishment of villages, towns and, subsequently, cities. Agriculture in the Fertile Crescent can, in fact, be said to be one of the major reasons for civilisation (Rackham 1994: 44).

Therefore attributes here could include-

Domestic fauna, as its presence could indicate evidence of domestication.

Wild fauna presence could indicate evidence of hunting.

As well as general data, indicating various types of human activity, for example, feasting apparent from dispersion patterns of remains, the following attributes can more specifically target associated human activity-

Element
Size
Fusions, Breaks, Modifications
-Proximal Anterior
-Distal Posterior
-Proximal Anterior
-Proximal Anterior

(Driver 2006 and Mathur 2006b)

Archaeobotany

The presence of domestic flora could indicate evidence of agriculture and, additionally, the presence of wild flora could indicate evidence of gathering.

Ecology

Local ecosystem sub-variants if present, rather than major biomes, for example sites located on prairies, compared to nearby valley sites can give some indication of site selection specificity.

Meteorology and Climate

Here, possible data can include-

> Wind speeds; minimums, maximums, averages and direction, possibly indicating such criteria as favourable sailing conditions.
>
> Maximum and minimum precipitation, indicating, for example, viability of certain crop species.
>
> Average air pressure, indicating, at extremes, maximum human tolerance or evolutionary adaptation, for example, the physical differences in the people of the Andes.
>
> Maximum and minimum daylight hours, indicating the seasonal availability of time for agricultural work.
>
> Maximum and minimum temperatures, indicating possible zones of comfortable human habitation.

Again, these factors can indicate site selection specificity.

Dating

Inclusion of data such as absolute radio carbon dates or relative earliest to latest occupation dates can also be use useful for site comparison purposes.

Other Archaeological Attributes

By this time it should be apparent that there are many, if not countless, subject areas from which one may select specific attributes for inclusion in any form of model including those pertaining to site location. It is for this reason that only common geographic and sociopolitical theory have been chosen for special mention. However, in order to continue, it is necessary to now draw this discussion to an end. In closing consideration could also be given to the following subject areas-

Behavioural Archaeology
Evolutionary Archaeology
Gender Archaeology

All can elucidate different aspects of site location and possibly merit rather deeper investigation than is possible within this body of work.

5.4 Final Selection of Attributes

It is hoped that the previous sections have, to some extent, illuminated the process of discovering data sources as well as useful attributes that may be included in a site location model. Attention is now turned to what attributes can be realistically selected for inclusion in the model for Harappan port locations given the data, time and resources available to this research. Thus, now that the raw data for the research has been assembled, the following section will be used as an opportunity to properly examine the selected data items, attributes or fields. The attributes selected are data items that can aid in site location by identifying distinguishing features thought to be possibly unique to the Harappan culture.

It should be noted that not all of these attributes are strictly necessary for the predictive model, but are still useful to the research as a whole. These attributes are ignored here as they are somewhat extraneous to any discussion of programmatic logic inherent within the model. Such attributes are those that include data of a more general nature, such as those concerned to do with general project administration such as site postal addresses or site director contact information.

Therefore, each attribute that is of use will be identified and its derivation described. It is also hoped that by careful selection of attributes now it may be possible to learn as to what can be accomplished in order to develop a more generic predictive model with specificity established through the supplied data. The specificity of data distinct to this particular research effort rather strays from this objective, though its use here is a necessary preliminary stage to later investigation into the possible future development of a more generic, so-called, "off-the-shelf" model.

Primarily it is important to attempt to use as much of the readily available data from the tabular forms described earlier. To reiterate, these are the data sets from the Possehl (Possehl 1999: 727-845) and Thakker (Thakker et al 2000: 5) research. Additional data has also been tabulated and these include, elevation (National Geospatial-Intelligence Agency 2009), altitude (Falling Rain 2009) and data describing the extent to which the sites in the Gujarat match the findings of the Gaur and Vora shoreline study (Gaur and Vora 1999)

Notably, all the data fields or attributes from the Possehl Gazetteer database are not used. This is because either some of the fields concerned with ports sites are null, that is, they contain no value, not even zero and thus cannot add intelligible efforts to the final analysis, or that the field is simply not relevant to the research, for example, if the field or attribute concerns an entirely different geographic area outside of the Gujarat. Therefore, bearing the above factors in mind, these are the final tally of attributes selected through the combination of the data previously described, as well as those derived statistically from a Matlab pattern matching program-

Name	Description	Source
nearer_gaurs_coastline_reconstruct	Site nearer?	Database
average_elevation_meter	NIMA elevation data	Database
average_altitude_meter	Falling Rain altitude	Database
harappan	Various cultural phases	Database
early_harappan	,,	Database
harappan_urban_phase	,,	Database
harappan_post_urban	,,	Database
kulli	,,	Database
sorath_harappan	,,	Database
late_sorath_harappan	,,	Database
late_harappan	,,	Database
jhukar	,,	Database
lustrous_red_ware	,,	Database
red_polished_ware	,,	Database
lower_indus	,,	Database
settlement	Site characteristics	Database
cemetery	,,	Database
average_size_km_sq	,,	Database
gps	Previous Reconnaissance	Database
excavated	,,	Database
explored	,,	Database
north_dist	Derived statistic (Matlab)	Pattern Matching
south_dist	,,	Pattern Matching
east_dist	,,	Pattern Matching
west_dist	,,	Pattern Matching
core_dist	,,	Pattern Matching
periph_dist	,,	Pattern Matching
most_sites	,,	Pattern Matching
least_sites	,,	Pattern Matching
cbt_uniformity	,,	Pattern Matching
nearest_neighbourliness	,,	Pattern Matching

Table 5.1 Final Selection of Attributes

A brief description of the derivation of each of the above attributes is now offered. So as not to become repetitive, it should be noted that the respective methods for dealing with text values and numerical values in each of the following sections is, to all intents and purposes, the same. All the data, except where Matlab code is used, has been extracted from fields in a table from a temporary database and subsequently processed programatically using the SQL language, a process that will be described in a later section.

5.4.1 Environmental Features

"nearer_gaurs_coastline_reconstruct"

The Gaur and Vora research (Gaur and Vora 1999) presents the case for, and the shape of, a reconstructed ancient coastline for the region during the Harappan period. The transposition of the results of this research using graphical tools has meant it has become possible to populate this field with a value in the form of a text string of either "Yes", "No" or "Submerged" as to the relationship an existing site location has with the proposed reconstructed coastline. Obviously submerged sites present a problem all of their own in terms of questioning the accuracy of the Gaur and Vora's research, though, here the concern is to find the average value, or most frequent value, of the state of a particular site given these researchers assumptions.

"average_elevation_meter"

Where NIMA elevation data exists (National Geospatial-Intelligence Agency 2009) for port sites in the region, it has been possible to extract the pertinent data from a downloaded text file using a variety of common UNIX command line tools. This data, fortunately, is small in volume. It has then been manually added to the database. It should also be noted that the NIMA data is not complete and many entries in the source file simply contain an empty string, that is, a null value. This is because the numerical resolution for NIMA data is not high. A simple average formula is used to obtain the final mean value, though its implementation is slightly complicated due to the need to count only rows that actually contain a non-empty string.

"average_altitude_meter"

To make up the shortfall in evelation data, numerical data concerning altitude has been gathered from the Falling Rain web site (Falling Rain 2009). It has been gathered by looking up the name of each port site from a web page alphabetical index. If the site is found, and this is not always the case, the value in metres is noted. After the data for each port has been collected from the Falling Rain web site, it is then manually entered into the database. A numerical average is then taken, however, again the paucity of data is to be noted as well as its unknown derivation from, supposedly, the NIMA base data (Tann and Flemons 2008).

5.4.2 Cultural Phases

"harappan"

A note should be made here about the "harappan" attribute. It has been included because during the process of selecting what fields should be included from the Possehl Gazetteer (Possehl 1999: 727-845), for the sake of inclusion and so as not to inadvertently omit a column that may later have some significance, it has been deemed prudent to include all columns that contain a port name and a non-null value even if at present it does not seem to have any current relevance to the model. This seems to be the case for the attribute "harappan" which appears to be somewhat redundant given the presence of attributes such as "early_harappan", "harappan_urban_phase", "harappan_urban_phase" and " harappan_post_urban". A fairly safe assumption is that it is included to differentiate sites that precede the Harappan culture sites in age, as well as those of the later historic period following the Harappan culture. Also although some fields indicate important phase information, they have been omitted because they contain no data.

"early_harappan"

This data is is also taken directly from the Possehl Gazetteer (Possehl 1999: 727-845). It is a simple text string with the values "TRUE" or "FALSE". It is an answer to the question of

whether the sites encompasses, chronological speaking, various cultural phases (Possehl 1999: 18). These phases are based on relative dating using evidence of material culture, later made somewhat more tangible by the gradual introduction of radio carbon dating techniques. Hence, in effect, most, though not all, of the Possehl sourced data is phase data in one form or another. This phase covered the period just after the transition from farming village communities, radio carbon dates show that this period started around 2600 BC (Possehl 1999: 23).

"harappan_urban_phase"

This is a relative phase, made up of several contemporaneous sub-phases (Possehl 1999: 23). It follows the "early_harappan" phase (Possehl 1999: 18). In terms of absolute radio carbon dates, it is thought to have begun at about 2500 BC (Possehl 1999: 23). This is the main period of Harappan activity encompassing the Mature Harappan period at 2600 BC to the decline beginning around 1900 BC. It is again textual data with a "TRUE" or "FALSE" value.

"harappan_post_urban"

This phase is made up of several non-contemporaneous sub-phases following the "harappan_urban_phase" (Possehl 1999: 18) and absolute radio carbon dating, dates the period from 1900 BC to around 1000 BC or the beginning of the early Iron Age in Northern India and Pakistan (Possehl 1999: 23). Again this field contains text of either "TRUE" or "FALSE" values. This post urban phase marks the start of the gradual decline of the Harappan Civilisation, though not its immediate demise as can be seen from the "late_harappan" sub-phase.

"kulli"

This attribute is one of five contemporaneous sub-phases of the Mature Harappan phase (Possehl 1999: 18). The absolute radio carbon dating of this phase is from 2500 BC to 1900 BC (Possehl 1999: 23). From Possehl's definition of his use of the term "phases" (Possehl 1999: 19) it can be assumed that this attribute infers a meaning of whatever

similarity in form a site may possess to the Kulli-Complex sites with their assumed upland extension of the Harappan culture (Possehl 1999: 104). Again, this is a textual string with a value of either "TRUE" or "FALSE".

"sorath_harappan"

This, like the Kulli phase, is also one of five contemporaneous sub-phases of the Mature Harappan phase(Possehl 1999: 18). Thus, the dating is also the same, with radio carbon dates from 2500 BC to 1900 BC (Possehl 1999: 23). According to Possehl, it is a regional variation of the Harappan Culture in the Gujarat and can be seen at such sites as Rojdi (Possehl 2002: 60) and three of Thakker's port towns in the Gujarat- Kuntasi, Valabhi and Mahua. It is a distinct culture for many minor reasons, however, one of the most prominent ways that it differed is in its sea-faring activities, with much Sorath Harappan pottery found in Bahrain (Possehl 2002: 60). This is textual of either "TRUE" or "FALSE" values.

"late_sorath_harappan"

This is one of nine sub-phases of the post-urban Harappan phase and is one of three of the oldest of these phases(Possehl 1999: 18). The dating is from radio carbon dates 1900 BC to 1600 BC (Possehl 1999: 23). As the name suggests it is also a regional variation of the Harappan Culture in the Gujarat varying in date and can be seen at Lothal (Possehl 1999: 790). It also consists of "TRUE" or "FALSE" values.

"late_harappan"

As it has been stated before, the post-urban Harappan phase does not indicate the sudden end of the Harappan culture or civilisation. It is for this reason that a late Harappan phase is seen in parts of India and with some material artefacts (Possehl 1999: 18). The radio carbon dates for this period range from around radio carbon dates 1900 BC to around 1000 BC (Possehl 1999: 23). Again, as it is also the case above, this is a textual field containing the values of either "TRUE" or "FALSE".

"jhukar"

This is another of nine sub-phases of the Post-Urban Harappan Phase (Possehl 1999: 18), however, the "jhukar" a sub-phase is very short, consisting only of one hundred years, radio carbon dated 1900 BC to 1800 BC (Possehl 1999: 23). The phase is distinguished with a characteristic pottery and is based on excavations at Jhukar, twenty-five kilometres north of Mohenjo daro (Possehl 1999: 84). The main difference between "jhukar" type pottery and classic Harappan pottery is that the manufacture of "jhukar" pottery involves an additional finishing stage where it is beaten after having been removed from the wheel (Allchin and Allchin 1982: 242). It also consists of "TRUE" or "FALSE" values.

"lustrous_red_ware"

This has been defined as one of the nine sub-phases of the Post-Urban Harappan Phase (Possehl 1999: 18). Further, radio carbon dating indicates dates of c.1600 BC to c.1300 BC (Possehl 1999: 23). This phase is characterised by a distinctive pottery type called "lustrous red ware". Examples of sites with this phase include not only the Beyt or "Bet" Dwarka island site in the Gujarat region (Possehl 1999: 738), but also Southern Rajasthan (Allchin and Allchin 1982: 262) and other regions (Allchin and Allchin 1982: 267, 277). The field also consists of "TRUE" or "FALSE" values.

"red_polished_ware"

This does not appear in Possehl's description of Harappan cultural phases (Possehl 1999: 18) and radio carbon dates (Possehl 1999: 23) because it is indicative of the first nomadic then dynastic Kushana culture starting around 200 BC (Chakrabarti 1999: 271). The period is characterised by distinctive red polished ware (Possehl 2002: 240). As it has been mentioned before, it has been included so as not to risk the possibility, however unlikely, of omitting any data pertaining to ports even if that data is thought to be of negligible value at present. It consists of "TRUE" or "FALSE" values.

"lower_indus"

This attribute, from further research is thought to be a possible reference to the Lower Indus Project (Possehl 1999: 298) concerned with changes in the course of the Indus River during the early Holocene. It is not mentioned in the phase chronology (Possehl 1999: 18) or the radio carbon dates (Possehl 1999: 23). A scrupulous manual search of the full text of the Gazetteer (Possehl 1999: 727-845) has not been made, however, this is in any case most likely to be irrelevant as the Indus River and its adjacent sites are far outside the geographical scope of this research. It also consists of "TRUE" or "FALSE" values.

5.4.3 Site Typology

"settlement"

There are a few non-phase attributes from Possehl's Gazetteer and, in this research, this particular attribute is grouped into a broad classification concerned with site typology. Although it seems strange to only include so few site type attributes into the model when there are other attributes available in the Possehl Gazetteer database such as "city", "town" and "camp", however, these fields unfortunately do not contain any data. This attribute consists of "0" or "1" numeric values.

"cemetery"

Another non-phase attributes from Possehl's Gazetteer, also grouped into a broad classification concerned with site typology within this research. Although the burial practices differ widely within the Harappan Civilisation, due to assumed variations in ethnicities (Possehl 1999: 32), some sites do possess what seems to be purpose built cemeteries, for example, Lothal (Possehl 2002: 81, 167). This attribute consists of "0" or "1" numeric values.

"average_size_km_sq"

By cross-referencing the published Gazetteer (Possehl 1999: 727-845) with the spread sheet version it has been possible to ascertain that the original, non-phase field 't' in the spread sheet contains the area of site coverage in hectares.

5.4.4 Field Work

"gps"

This non-phase attribute sourced from Possehl's spread sheet version of the Gazetteer (Possehl 1999: 727-845) give some indication of whether any previous field work has been performed and perhaps provides a small indication of whether the geographical coordinates can be trusted. It also consists of "TRUE" or "FALSE" values.

"excavated"

Another non-phase related attribute sourced from the Possehl Gazetteer (Possehl 1999: 727-845) indicating whether more detailed, fieldwork has taken place. This attribute consists of "0" or "1" numeric values.

"explored"

This non-phase related attribute sourced from Possehl's spread sheet version of the Gazetteer (Possehl 1999: 727-845) indicates whether at least preliminary reconnaissance has occurred. It should be noted that this type of data and, in fact, all data pertaining to fieldwork is almost certain to be out of date, therefore, it is of limited use in determining the potential for undiscovered sites nearby. This attribute consists of "0" or "1" numeric values.

5.4.5 Distribution Pairs, Percentage

These attributes are indirectly sourced via a Matlab pattern matching program created for this research. The program begins by creating a virtual map by identifying the port sites (Thakker et al 2000: 5) located at furthest cardinal points, that is, furthest north, furthest, south, furthest east and furthest west. With this virtual square, the entire map can be halved and then quartered, both vertically and horizontally allowing the entire geographical extent of the area containing sites to be divided into different, but equally sized zones; north, south, east and west and core and peripheral zones. The program then counts the distribution of sites within these different zones and compares the paired zones, such as north and south, east and west and core and peripheral zones and these counts are then expressed as percentages.

<u>"north_dist" / "south_dist"</u>

In this case the extent is divided into north and south regions and the southern sites are counted.

<u>"east_dist" / "west_dist"</u>

Here the extent is divided into north and south regions and the eastern sites are counted.

<u>"core_dist" / "periph_dist"</u>

In this slightly more complex variation the extent is divided into a core at the centre, surrounded by a periphery region and the sites that lie within the core region are counted.

5.4.6 Distribution Density

"most_sites" / "least_sites"

Here, every previous site count for each zone is compared to each other in order to extract the highest numerical value for site numbers, which, logically, will contain the most sites and the zone with the lowest numerical value will contain the least sites.

5.4.7 Geographical, Social and Political Models and Probability

These attributes are again indirectly sourced via the Matlab pattern matching program created for this research that counts the distribution of all the Thakker port sites (Thakker et al 2000: 5) within different zones of the geographical extents and then performs percentage calculations.

"cbt_uniformity"

This is an attempt to determine how uniformly spread out the sites are overall. Here the percentage difference the between core and periphery areas is measured. If the overall value is greater than half, it is deemed to be significantly uniform.

"nearest_neighbourliness"

This is an attempt to determine how clumped together or clustered the sites are overall. Here the percentage difference between each regional pair, for example, east and west is measured and if the overall value is greater than half, it is deemed to be significantly clustered.

5.5 Software Review

This research is driven by computer technology. This is true, particularly in respect, of obtaining tools required for construction of the computer-based predictive model. Because

of the complexity of the research, many false starts have occurred due to choosing a tool for a critical task, only to have that tool fail, usually, in an unexpected manner. This is most evident and, in fact, typical in the field of databases and working with large files. This has lead to considerable time loss. Thus, a review of each tool and its use in the research has been compiled in the hope of offering some ideas of a useful tool-set to future modellers.

5.5.1 Standard Office Software

Open Office Portable 2.2.1, with Java Runtime Engine (JRE) is an open source Office Suite (https://sourceforge.net/projects/portableoo/). It has been used for producing most of the main documents for this research as well as for some of the database work. It is a good approximation of Microsoft Office 97 Professional and is considerably easier to use version from Microsoft of Microsoft Office 2007 Professional . A notable recent development is the choice to use Open Office in preference to Microsoft Office by Oxford Archaeology, a large practice in the United Kingdom, mainly for reasons of cost and open standards (Oxford Archaeology 2009).

Microsoft Office 97 and Microsoft Office 2007 Professional has been used infrequently on this research due to file compatibility issues, particularly with regard to database issues. Attempts have been made to to develop the predictive model database software using Microsoft Access because of past, professional experience, however, due to the need to make this data easily available to others in the post-research phase, it has been abandoned in favour of the more compatible SQLite.

Atlantis 1.6.1.5 word processor; this secondary word processor used rather infrequently at the beginning of the research due to its need for no subsequent re installation when moving to a new computer systems is extremely advantageous because all user settings are kept in a locally stored configuration files rather than the shared Windows registry. Its installation size is also small. Although, like Microsoft Word, it too can also be configured to use reversed video in order to reduce eye-strain. It offers almost complete compatibility with Microsoft Word if one is cautious not to use Atlantis specific formatting such as differing

footnote design. A useful addition for non touch typists is the "Power Type" feature which will attempt guess which word the user is trying to type. For archaeologists this is immensely useful as there are many difficult spellings and long words both in the science of archaeology itself and, most particularly, in complicated place names. One major disadvantage, however, is its lack of support for creating tables, a feature frequently used in most scientific research papers. Its use in this research has now diminished as all functions found useful in this program, have now been superseded by those found in Open Office.

PrimoPDF is a free Adobe PDF printer driver. That is, it permits the creation of the popular Portable Document Format (PDF) files from any source file that can be printed. It does this by creating a virtual printer that other programs can use to print from. The result of this print is the creation of a new PDF file. The benefit of using this format is that the resultant PDF files are much smaller than their original sources, because it includes algorithms to compress graphics, it is ideal when it is required that papers to be uploaded to a web page or e-mailed. The tool is useful in both lectures concerning this research presented at Simon Fraser University and for the contribution to the conference *Computer Applications in Archaeology* in 2006 (CAA 20006). In the case of the former, it has been used to supply both undergraduates and graduate students with lecture notes. It has also proved useful in this research during times when there is a need to collaborating with other researchers because it allows for the user to send papers in a format that is not easily altered, as opposed to an easily editable document in Microsoft Word format. As Open Office is also able to convert Microsoft Word documents into PDF and, therefore, its use has diminished within this research.

5.5.2 GIS

ArcView 3.3; this relatively simple GIS suite has been chosen mainly because it is the only ESRI product that easily installs on a standalone PC. In fact, although long replaced by many succeeding versions, version 3.3 is still the standard GIS suite used in industry simply because of the overly complex later editions. Its use on this research has been pivotal as it allows for the integration of various imagery as well as database information

to be consolidated into a single storage area. It also helps in categorising and cataloguing the data used in the research; graphical, numerical and textual data for much greater ease of administration over the long and varied course of the research. It should be noted that QGIS, a simple GUI interface to the grass GIS has matured in utility during the course of this research, is as simple as ArcView to use and much simpler to install, it is also free and open source.

AutoCAD 2000, AutoCAD is, of course the standard computer aided design tool. Also AutoLisp, a simplified sub-set of the LISP (LISt Processor) programming language has also been retained from earlier versions of AutoCAD so that third party scripts can be used and simple procedures automated using AutoLisp macros. This has been used to occasionally model structures and to import third party models from elsewhere. In addition, this version of AutoCAD seems to be the most compatible over a range of 32 bit Windows operating systems, that is, from Windows 2000 to Windows XP.

As it is an industry standard package used by both architects and archaeologists, the drawings produced can be easily be exported to other formats.

5.5.3 Programming Tools

SQLite 3.4.0 (http://www.sqlite.org/) is a Relational Database Management System (RDBMS), though extremely lightweight and simple to use, it is powerful enough for the requirements of this research. It is available in several forms, including as an external library of functions that can be called from another program and a standalone executable that can be used either directly or from within a script. Occasionally, SQLite Database Browser 1.3 (http://sqlitebrowser.sourceforge.net) a GUI for SQLite has been used to check and test SQL code. Since the time of writing SQLite has been used by major companies such as Nokia in prototype GIS applications for hand-held mobile devices such as the Nokia internet tablet (Rubio 2009).

Matlab R2007b (http://www.mathworks.com/) is an industry standard mathematical programming application used throughout the scientific community. Its original design

was that of a simple command line interface to the Fortran LINPACK and EISPACK mathematical function libraries (Moler: 1981) so that science students were able to perform various mathematical tasks without little or no skills in programming. Over the years this has grown into a large and powerful program that can help to solve problems in many domains. Of particular interest here, however, is that it has built-in GIS capabilities that are very easy to use and powerful. It is for this reason that this program has been chosen for the pattern matching component of the predictive model. Matlab is an fairly standard academic tool and has been used in many archaeology based applications, for example, to digitally analyse dental features (Wall and Wall 2006: 1153) and a digital manipulation history tracing program (Kennedy and Chang 2008: 356) to name but a few. This has been replaced with FreeMat in the final incarnation of the software (Basu et al 2009) due to size, cost and installation issues.

Microsoft QBASIC 1.1 (http://download.microsoft.com/download/win95upg/tool_s/1.0/w95/en-us/olddos.exe) is an interpreter for the old DOS structured BASIC dialect from Microsoft which can still runs on the newer Windows XP without any problems. It is a simple dialect of Beginners All-purpose Symbolic Instruction Code (BASIC) and has been of some use as a simple formula calculator and for other ad hoc research tasks.

StarLogo (MIT Education 2005) is an agent based simulation language developed by Mitchel Resnick and others at MIT Media Lab and MIT Teacher Education Program. It is an multiple agent based extension of the Logo programming language and can used to model decentralised systems. The term "agent based" means that the language can allow the user to model decentralised systems, that is, systems where there is no one central command, such as swarms of bees, traffic jams or flocking birds. StarLogo has been developed from a need to extend the Logo language designed for education; the language is syntactically similar to Logo and like Logo, itself a sub-set of the LISP language, it permits the user to control "turtles". These turtles can draw lines across the computer screen. Finally, it should be noted that StarLogo can be classed as a massively parallel language. This means that each of those thousands of turtles can perform their individual actions at the same time (Resnick 1994: 33). Although other languages including such languages as NetLogo, SWARM, StarLogoT, Agentsheets, Ascape and Repast have now

surpassed StarLogo in agent based simulation, it beats the others for its sheer simplicity and for rapid prototyping. StarLogo is particularly well suited for artificial life and simulation projects (MIT Education 2005). Is agent based programming capabilities have been used in this research to demonstrate various factors concerning the speed of various transportation types available to merchants of both the Harappan Civilisation and Mesopotamia.

Borland Turbo ProLog 2.0 is a popular and simple variant of the Prolog (Programming in logic) language (Clocksin and Mellish 1987). Its use in this research has been as one of the tools from which one can learn about artificial intelligence, particularly expert systems. Although not used as an industry standard tool since the 1980s, it is, never-the-less, a simple and well-designed programming environment. Several expert system example programs are available from various sources, such as a geographical database that comes with this software (Borland 1988). Because of its immense popularity in the mid-1980s, it is also a good choice as there are many books available for learning the language. This cannot be said, unfortunately, for many of the more modern variants of Prolog. One aspect that should be noted is that Turbo Prolog does not conform to American National Standards Institute (ANSI) standards for the Prolog language, though it is still used in many universities today to teach the basic concepts of artificial intelligence. It should be noted that the Prolog language is not the same as procedural languages. Program design in Prolog is primarily involved in describing what is required, rather than how those requirements should be achieved. It has been said that "this is far more natural than the procedure-oriented way of looking at microcomputers" (Shafer 1987:4).

MySQL 5.0 (http://www.mysql.com) is a freely available, open source RDBMS. It is, however, overly complex for this research and subsequently has been replaced with SQLite.

Regina REXX 3.3 http://regina-rexx.sourceforge.net/), is an extremely flexible interpreted scripting language, that is, a programming language for writing short, macro-like computer automation routines. Compared to Perl, the most popular scripting language used by millions of users, it is much smaller than Perl and the code is much clearer to read. Although, originally developed for mainframe computers, it has been ported to just about

every operating system and hardware platform. Also with the development of external function libraries, it is also powerful and its uses can be extended beyond simple automation or string manipulation. For example, there are libraries that are particularly useful for this research, such as, to connect to a database and to manipulate graphics. Although a simple language, code developed in Rexx, or for that matter Perl, does have very unique features that are difficult to translate into other languages. Since part of research aims is to eventually attempt to produce a commercial grade product, readable and well commented code is vital for future translation or upgrades. QBASIC is so simple in design that, if well written, the code can almost resemble pseudocode ans is therefore used in preference to Rexx.

Perl 5.8.7.822; this is an interpreted language originally created by Larry Wall while at NASA's Jet Propulsion Laboratory. It is used, primarily, as a scripting or "glue language" and a way of easily tying together different programs, tools or utilities. It is also used in web applications to run programs on a server, the so-called Server-Side Includes (SSIs) or Common Gateway Interface (CGI) programs. Its name is an acronym for Practical Extraction and Reporting Language, which reveals its origin as a tool for creating reports from text. It is this utility that has been initially of use in the research. Early in the research there was a requirement to split columns of data into separate variables for further processing. While this can be done in other languages such as BASIC, this function is pre-built into Perl. In fact there are hundreds functions within many libraries that extend the usefulness of Perl. Also, its large community of users means that, although it is not visually the cleanest language, novice developers have ready access to consult with other more experienced users in many online forums. Although, it seems like a main candidate language for creating the predictive model, problems with this particular version of Perl means that it has been dropped from the research. Problems consisted of compatibility issues between it and many external modules needed to create the predictive model. Batch scripting using UNIX utilities, such as "sed" and "grep" ported to Windows has taken the place of Perl.

5.5.4 Text Editors

GVIM/VIM 7.1+ for DOS32/Win32 (http://www.vim.org) is a much enhanced version of the ubiquitous "vi" screen editor for UNIX. Although,it has a steep learning curve it has been chosen due to past familiarity. It is a modal text editor in that there is a different mode for editing, navigating and issuing commands. It is also highly extensible, that is customisable, with its own internal scripting language "ex" though, in fact, any language can be used. For example, batch commands can be run from within the editor. The drawback is that there is a steep learning curve for users unfamiliar with vi, though less than for users of the other, almost as wide-spread, UNIX text editor EMACS. It is the main text editing tool used in this research and can do almost all tasks required of it. It is in this research to write programs, read very large text files and to display text correctly from the output of the predictive model.

Programmer's File Editor 16-bit Edition 1.01.000 (http://www.lancs.ac.uk Kingdom/staff/steveb/cpaap/pfe/). This is another plain text file editor. In itself, it is usable and, except for the lack of syntax colouring, it is quite acceptable as a simple editor. Where it really excels, though, is in its role as search and replace tool. Although VIM, the main main text editor used here, does have complex regular expression search capabilities, it does not have a simple way of searching and replacing character strings. PFE, however, does this, using very simple notation. Also, like VIM it can save and open very large files, of both the UNIX and MSDOS variety without crashing. The older Windows 3.1x version of the program has been used because of its registry-free configuration. All settings are stored locally in an ".ini" file and hotkey assignments in a ".key" file.

Crimson Editor 3.72 Portable Version 236 (http://www.nullsoft.com and http://www.emeraldeditor.com) This is a simple to use and configure multi-syntax plain text editor. In other words it is a complete computer programming language environment for many different computer languages. It has been a particularly important tool to use on this research as are a number of different languages used and it can be tiresome to learn a different and proprietary Integrated Development Environment (IDE) for each new language. With this software it is possible for the user to configure compilers and

interpreters for up to ten programming languages. During this research, it has been configured to work with Perl, Rexx, SQL, QBASIC, Java, HTML, Prolog, AutoLISP, StarLogo and Javascript source code. For some languages, such as Turbo Prolog, a syntax file has had to be created as no ready-made file is available for download. This syntax file mentioned has also been uploaded to the Crimson Editor web site so that other users may benefit from it. These syntax files are useful in assisting the programmer by highlighting keywords or functions unique to each programming language. This greatly eases tasks such as debugging code. A further feature of Crimson Editor is the built-in file transfer protocol (FTP) client. This is useful when making small changes to HTML files on the research web site at York or its mirror. Its use in the research, extensive at first, has lessened after numerous crashes when opening very large files, such as the combined harappan database used in the predictive model.

5.5.5 Graphics Manipulation Programs

Paint Shop Pro 5.03 (http://www.jasc.com/) has been selected for its simplicity and speed for editing raster graphics files of most formats. It triumphs over the standard graphics suites such as Photo Shop and later versions of Paint Shop Pro itself in many ways. First, in its ease of use. Unlike larger suites such as Corel and,ultimately, the graphics industry standard- Adobe PhotoShop, it has low resource requirements. It is not, however perfect and does lack useful features such as vector graphics. This version of Paint Shop Pro, although old, scores over its later versions and other suites with its shallow learning curve, consistent interface and simple layout. It is, however, important to emphasise the usefulness of a good graphics program to the landscape archaeologist. Topographical maps, site maps, satellite imagery and aerial photographs can be cropped, resized, rotated and magnified. Most importantly it can be used to prepare imagery for import into a GIS package. In fact, it has been used in all the above ways on this research, that is, from preparing imagery for inclusion in the text and to ready imagery for loading into ArcView as well as tasks such as testing the Matlab component of the predictive model.

IrfanView 4+ (http://www.irfanview.com/) is a very useful image viewer for almost every image format. It also has some editing features such as select, crop, rotate and resample on a singular and batch basis, saving much time when working with large groups of image

files. This feature has been useful to the research in that it has enabled the processing of large batches of graphics files prior to loading them into ArcView. Its thumbnail picture preview function is also much faster and more flexible in operation than those of commercial grade photographic manipulation packages such as Adobe Photoshop. The program also allows the creation of slide-shows, either for use in presentations or compiled into single executables for general distribution. It is so good at these tasks that it replaced Microsoft PowerPoint as the presentation tool of choice for this research. Its small size and ease of installation proved of added benefit.

5.5.6 Internet Tools

Kompozer 0.77 Portable is a replacement for the outdated NVU 1.0 (New View) "What-You-See-Is-What You-Get" (WYSIWYG) web page editor. Creating web content with a WYSIWYG editor is much faster than writing raw HTML code. For more advanced web programmers it also allows editing of cascading style sheets, insertion of PHP code and a console for debugging Javascript. It has been used in this research to publish abstracts and publications to the research web site.

Firefox 3.0.3 (http://www.mozilla.com) is a free, open source web browser based on Mozilla, an open source replacement for Netscape Naivigator. It is the web page browser of choice for this research for a variety of reasons. Initially chosen because it is much faster than Internet Explorer and less prone to crashes. Its use of tabbed browsing, that is, the opening of many different web pages in the same browser under different tabs, rather like an old-fashioned pop-up address book has allowed the creation of scripts to automatically submit hundreds of web searches in a matter of seconds. This has been of great benefit in terms of time saving during this research. Firefox also has a much better interface than other browsers for querying online search engines that are particularly useful to the archaeologist. For example the browser has been configured to multiple search engines provided by the New Scientist, Smithsonian Museum and the British Museum amongst others. This cannot be an exhaustive list of features that would require to much time to discuss, however, one last feature worth describing is the multiple proxy feature. Archaeological researchers based at universities may sometimes need remote access to the

various online services that are only available via a campus computer network. For example, the JSTOR scholarly articles database. Firefox also enables the quick change of proxies, through an extension called "Multiproxy Switch" so that it is has been simple to login to the York Campus remotely.

5.5.7 Operating Systems

Windows2000/XP/Vista, a t its inception and until the late middle phase of the research Windows 2000 has been the standard operating system in use on the research desktop computer. It has been chosen for its stability and increased device and peripheral support over and above Windows NT 4.0. The original desktop PC was however, replaced with a laptop running the new Windows Vista operating system. This has proved initially disastrous, as much of the software described here did not function under this new operating system. In order to alleviate this problem, solutions from various internet forums were sought. The solution required that Windows Vista is replaced by the version of Windows XP Professional mentioned in the above title of this section. Windows XP Professional appears to be fully capable of running all the software that is used on this research. However, it should be mentioned that this is a heavily customised, non-standard version of Windows XP. Later in the research as software has become more Vista compatible, these initial concerns have dissipated.

5.5.8 Interactive Shell Tools

As well as a customised shell for the operating system command console, also known as the DOS prompt, three additional interactive utilities have been designed to allow lines of programming code to be entered and immediately evaluated. This is invaluable in assisting to learn different aspects of unfamiliar programming languages rapidly. These interactive utilities also serve as a single line calculator. Interactive shells have been written for Perl (Appendices: rps.pl), Rexx (Appendices: rsh.rex) and QBASIC (Appendices: rqs.bas).

5.5.9 Other Software

This is by no means an exhaustive list and many other tools were used, if somewhat briefly for a variety of purposes. However, what is provided here is the selection of tools found to be the most useful during the research.

5.5.10 Hardware

For the first half of the duration of this research a PC based desktop is used. This has been replaced with a fairly standard Toshiba laptop, mainly due to travel requirements. A possible note for consideration to future researchers is the difference in video capabilities of both systems. Much of archaeology today relies on 3D modelling of either artefacts, or more usually, buildings and monumental architecture. If the research had need of 3D modelling tools, such as 3D Studio Max or Maya, then both the above systems would be found to be severely lacking. Even with the much improved graphics of the second system, it could still not even aspire to run these applications. 3D graphics applications required powerful, and expensive, graphic sub-systems. One last consideration for the travelling archaeologist is that battery life should be a prime consideration, this is particularly the case for high power consuming components such as high performance graphics cards.

5.5.11 Multi-platform, Free and Open Source Software

During the course of the research, while researching for useful software tools, it has become apparent that for almost every piece of commercial software there is an open source equivalent available free of charge. Examples are Open Office as an equivalent to Microsoft Office, GRASS as an alternative ArcInfo, QGIS; a GRASS based a replacement for ArcView and Gimp as a replacement for PhotoShop. However, for many reasons, including lack of familiarity with the tools and the fear of taking, a not inconsiderable amount of time to learn a tool that may suddenly become unpopular, it may be sometimes considered beneficial to stay with commercial software. Given the growing maturity of the

open source movement, this may change in the future. This will be to the benefit of archaeologists who usually have better uses for spending limited project budgets. A somewhat brief explanation open source licences must make the source code available to all (Thomas 2007: 15). Software is usually, but not always free of charge. For a fully explanation the reader is advised to type "FSF" into an internet search engine (Thomas 2007: 17).

The one other reason for favouring open source has to do with the portability of software across different hardware and software platforms. The obvious benefit of this is allowing users to concentrate more on learning to use the software irrespective of the platform it runs on. More recently there has also been a movement called "Open Archaeology" which state the desire to embrace open standards by sharing data and also using open source software (OpenArchaeology.net 2009).

5.5.12 Software Preferences in this Research

A final point to consider is that in this research there has been an increased reliance on alternative tools to those generally used by the majority of computer users at present. For example, for most of the database needs of this research SQLite replaced Microsoft Access. Although there are many detractors of Microsoft who reject the company's products on various ethical and aesthetic grounds, there is no such philosophy on this research. The tools that provide the greatest utility have been chosen. In this case, however, the tools most efficacious happened not to be those originating from Microsoft.

Thus, in closing, the most useful tools for this research have been Open Office, SQLite and VIM. Tools such as QGIS also bear watching for future developments.

5.6 Concepts

Here, the various concepts and technologies that are to be used in developing the predictive model are explained.

5.6.1 Data Mining

It could be said that this research is an exercise in data mining. The purpose of data mining is, succinctly defined, as a way to "sort through large quantities of data and discover new information", that is, to identify "hidden patterns and relationships within the data" (Groth 2000: 3-4).

Whereas corporations use data mining to gain competitive advantage, archaeological scientists can use the tools available to sift through the mountains of data that they are often confronted with. In the case of this research, it can be said that there are rich seams of stored data that could potentially be harvested, mined or re-interpreted from existing sources by an archaeologist versed in the basics of computer programming, thus, it is at this interface between computer science and archaeological science that this research hopes to build upon.

Therefore, in order to access useful information within the corpus of all the research data, there is a requirement to provide an efficient storage medium. Here "medium" refers to the logical storage schema rather than the actual physical medium of, for example, disk drives or optical disks.

It has been decided at the onset of the research that a Relational Database Management Systems (RDBMS) should be used for handling all research data storage requirements. Although, as we have seen earlier many Geographical Information Systems (GIS) are available with internal RDBMS tools. For example, ArcView can utilise and store data internally as DBase format files; DBase being a industry standard relational database format. However, it has been deemed simpler and also more cost efficient to use external third party software for the data storage needs of the research, this is because of the rather proprietary way that GIS applications have implemented RDBMS functionality.

This research is not, of course, the first time GIS has been combined with an external RDBMS and other organisations have also explored more efficient ways of combining

relational database systems with GIS. An example of this can be seen in the Isobord manufacturing company investigation of various combinations of these two kinds of software in 1996 (Neufield and Griffith 2006: 64-80).

Hence, with the importance of RDBMS to this research, it is logical to begin with a brief explanation of the relational databases.

5.6.7 Relational Database Management Systems

The relational database, although the predominant type of database in use today is not a new idea and, as originally defined by Dr. Edgar Codd at IBM (Codd 1969), it is basically a system of storing tables of data that relate to each other.

This has distinct advantages over the old flat-file databases, that is databases consisting of only one table in the form of a file, in that the amount of data the user has to input can, in some circumstances, be much less.

A simple explanation of how this works can be seen from the following example. For instance, in a finds databases, each row of data describing a find does not have to include the entire site address. The site address, in fact, only needs to stored once and then linked to each find by a common identifier, that is, a single column that is the same in each table. See the following examples-

First consider the one large table of finds consisting of one flat-file database:

Finds Table

ID	Name	Address	Find ID	Find	Description
B1	Bobton	Bob Street	F1	Broach	Bronze Age
B1	Bobton	Bob Street	F2	Dagger	Iron Age
B1	Bobton	Bob Street	F3	Skull	Undated human

As can be seen, the address data has to be repeated three times; once for each of the finds records.

Now consider the same data, but using the relational database schema which entails the creation of two tables, one for the site data and the other for the finds.

Site Table

ID	Name	Address
B1	Bobton	Bob Street

Finds Table

ID	Find ID	Find	Find Description
B1	F1	Broach	Bronze Age
B1	F2	Dagger	Iron Age
B1	F3	Skull	Undated human skull

Now address data is only required to be entered once, because the Site ID column in the Finds Table is sufficient to link each find to its corresponding record to the address in the Site Table.

If one is to imagine a team member entering data at a site, then it is not difficult to comprehend how relational databases can save considerable entry of data.

In relational database terminology this table linking feature is achieved through a complex mathematical system based on set theory. The analytical process of transferring repeated data is commonly known as the removal of repeating groups to another table or, to use a more technical term, normalisation. Again, although how this works involves complicated mathematical proofs, its practical use is fairly simple and useful.

Also a structure that allows data to be joined in this way makes RDBMS a very powerful query tool. As long as there is some way to import various externally obtained raw data tables, for example, in the form of comma separated values in text files, and then join them to existing data, there is virtually no limit as to how the data can be queried.

Another distinct advantage of using relational databases is in the abstraction of the data away from the code of the program. In other words, when changes occur in the code of an old-fashioned database program, for example one written in BASIC, there must often be changes in underlying data. In relational databases this is not the case; changes to the way the data is accessed do not have to involve changes in the structure of the database itself.

5.6.8 Structured Query Language

The data in both types of the above database, both flat-file and relational, are held in tables, how this is achieved is actually fairly abstracted from the interface layer of the programmer and even more so from the end-user. With certain qualifications regarding the actual RDBMS product used and side-stepping the issue of Graphical User Interfaces (GUIs) of the various database systems, the programmer only needs to understand the main aspects of Structured Query Language (SQL), pronounced either "ess-q-ell" or "sequel". This is a computer programming language designed specifically for RDBMS. It is also-sometimes known as a Forth Generation Language or 4GL, supposedly nearer to human language than other Third Generation Languages (3GL) such as FORTRAN, BASIC, C and in fact most of the popular programming languages of today. Second Generation Language (2GL) is a language such as assembly language and a First Generation Language (1GL) is pure binary machine code. To shorten the explanation, the following concisely describes the developments in computers technology and the corresponding development of computer programming languages.

<u>The Evolution of Computer Programming Languages</u>

Generation	Type	Example
4/5GL	Human language	English
4GL	Query	SQL
3GL	Procedural	FORTRAN, BASIC
2GL	Assembly Language	Turbo Assembler
1GL	Machine Code	1s and 0s only

This is, however, not to say that SQL is a simple language to learn and, in many ways, it is actually inferior and difficult to use compared to some, more versatile, lower-level languages such as C. This is because the SQL language is based around set theory and thus, it is difficult accomplish tasks in SQL that would be simple in other languages, such as putting the results of a query into a variable for further processing, though the designers of SQL are hardly to blame as it was not the original intention to build such functionality into the core of the language. In order to overcome these problems, there are many instances today of where SQL code can be embedded into the code of another language.

To give brief examples of SQL in action, there are two forms of SQL. The first type, Data Definitional Language (DDL) which is used to build the database, the other, Data Manipulation Language (DML), is used to query the data. See the following examples.

SQL DDL Example

```
create table tbl1(one varchar(10), two smallint);
insert into tbl1 values('hello!',10);
insert into tbl1 values('goodbye', 20);
insert into tbl1 values('hi!', 20);
insert into tbl1 values('bye', 20);
```

This builds the table "tbl1" with two columns- "one" and "two" and then populates each column with the two rows containing data "hello!", "goodbye" and "hi!", "bye" respectively.

SQL DML Example

```
select * from tbl1;
```

This queries the table just create and returns all values therein.

Finally, and example of, SQL embedded into another language, in this case Rexx.

Embedded SQL

```
removeIt = "delete from tbl1",
"where one = ‘hi’"
"sqlexec" removeIt
```

Here some SQL is stored in the variable "removeIt" and then executed later with the Rexx add-on product DB/REXX or SQL/EXEC (Goldberg and Smith 1992: 441).

Now that an explanation of database technology has been offered some case-studies of database use in historical research are offered

5.6.9 Databases in Historical Research

Example One: zooArc 3.0

The usefulness of RDBMS technology in archaeology can be seen, for example, in the lab where one might be storing zooarchaeological data using simple software derived from Microsoft Access. An example of this is the zooArc 3.0 application (Mathur: 2006b). This simple application allows zooarchaeological data to be stored in a uniform manner for later query. It is more efficient than a simple spreadsheet because it can be configured to rigorously validate data, which enables time-saving because future entries do not need to be cross-checked for accuracy.

Example Two: Temporal Document Retrieval Language

Before the subject of SQL is closed, one last point to note is that there have been attempts to customize SQL for certain professions, much in the same way as the internet language XML has been customised for different trades, for example ChemXL for the pharmaceutical industry. One such attempt of particular interest to researchers in social science and the humanities, is the Temporal Object-Oriented Document Organisation and Retrieval (TOODOR) database and its associated language Temporal Document Retrieval Language (TDRL). It has been designed by a Spanish team of researchers and created to facilitate the retrieval of historical documents by non-experts. It strongly resembles SQL, in this respect, but with some added enhancements and abstractions so that academics and scholars can concentrate on the historical research rather than learning computer skills. (Aramburu and Llavori 1998: 216-225).

The above examples show the depth of investment there is in these technological advances and the possible gains that can be made by selecting the most appropriate tool for the task. The converse is also true, however, as can be seen from the next example.

Example Three: Object Retrieval/Entry System (ORES)

An experimental system has been developed by the researcher to replace the Museum Object Documentation and Entry System (MODES) database at Bromley Museum in the United Kingdom. This is a database system used by many British Museums to catalogue their collections. It is not relational and is programmed in fairly archaic Pascal and designed to run in the old personal computer operating system MSDOS. It works well though, it is not the easiest system to use. Its files are organised in an old hierarchical manner. The file structure, programming, language and user interface are so out-dated that it has been thought that a cleaner, easier to use system designed in Microsoft Access could alleviate these problems. It has not been until well into the development phase of the research that it has been realised that there is a valid reason why the replacement can not be made to compete with the existing system. The reason for this is that the old MODES system works on the premise that the data it has to store is, in fact, hierarchical in itself which was why the MODES programmers have programmed the database in a hierarchical manner. Whilst it is possible to emulate this structure in Access, it would not be as efficient as the older system. Therefore, the new system called Object Retrieval/Entry System has eventually been put aside and the older system retained (Mathur 1995). The successor to ORES, ORES 2.0, however, has later been successfully implemented as a simple cataloguing tool for museums where hierarchical data specification is not an issue (Mathur 2006a).

In this research, however, it is useful to learn from past experiences and simply use the tools that are best-suited for the task ahead, rather than using technology for its own sake.

5.6.10 Other Concepts Utilised in this Research

Statistical Analysis

A better understanding of the purpose of this research can be gained by a brief glimpse of the research of Pidot and Somer into statistical commonalities between cities for the Environmental Protection Agency (EPA) in the United States of America entitled *Modal*

Cities. They have been attempting to demonstrate how to "classify urban areas...into a small set of types based on their economic, social and demographic characteristics" (Pidot and Somer 1974: 5). This is not so dissimilar from what is trying to be achieved in this research. Here they have identified three major methods that have been used in the past for the basic classification of towns. The first being employment figures, by specific industry, figures from one city are compared to those used to classify other cities. The weakness here being that this criteria is heavily influenced by the initial choice of city. Alternately, a calculation of "arithmetic mean with associated standard deviations" is used to classify the positive or negative correlation of a specific industrial sector between the mean and each member of the sample group. Or, thirdly, by selection of an "arbitrary majority quantity...as a yardstick" (Pidot and Somer 1974: 2-3). Pidot and Somers follow stating that, in their own research, they have expanded their choice of classification variables to forty-eight factors including population, employment, income sales and expenditure by industry (Pidot and Somer 1974: 7-10). To a lesser extent, this concept of statistical analysis has been applied to this research, though, at the same time attempting to avoid, through use of well designed algorithms, situations that may lead to skewness (Caswell 1982:118) or kurtosis (Wikipedia 2009: kurtosis) where mathematical extremes can produce abnormal results.

5.7 GIS Construction

The benefits of GIS as a tool for archaeologists, planners and geogrpaphers is well documented in various works such as, for example, during a study in Greece, researchers have found that several issues pertaining to the use of GIS techniques (Bevan and Conolly 2004: 135).

They have found that by using different scales of data collection and field work for map, photographs and geoarchaeological data, it has been possible to determine the transition from one agricultural strategy to another (Bevan and Conolly 2004: 136).

They have also determined that visibility, in terms of survey team and artefact recovery, although a useful variable, is not a simple way to change calculations of density (Bevan and Conolly 2004: 136).

The researchers believe that, on a large scale when regarding a continuous surface of archaeological material, fall-off patterns can be reliably and meaningfully defined for sites; this is useful for understanding site formation processes and a better approach for site-definition (Bevan and Conolly 2004: 136).

Finally, they have discovered that multi-scale techniques to look at terrain ruggedness, when combined with watershed scales, emphasise that human decisions about site locations reflect considerations that involve multiple scales of the environment (Bevan and Conolly 2004: 136).

They conclude by stating that they have identified various of the patterns underlying modern and ancient landscapes, as well as, some of the factors influencing and governing site identification and definition in an environment with a high content of artefacts. (Bevan and Conolly 2004: 136). Additionally that GIS approaches are valuable and, while further work is necessary using both more detailed chronological and geomorphological data, it is thought that the initial analysis demonstrate the method in combining multi-scalar data in useful ways that may lead to a better understanding of the archaeological record (Bevan and Conolly 2004: 137).

Experience during this research has demonstrated the usefulness of GIS based computer software as shall be seen in the following section.

5.7.1 ArcView

There are many publications that already explain how ArcView works, but it is prudent to, at least include a brief introduction here. This is a lower-tier an less complicated Geographical Information System (GIS) application from the Environmental Systems Research Institute, Incorporated (ESRI). It contains some of the same functionality as its

highly sophisticated sibling ArcInfo. It is a highly graphical computer software program designed to assist in analysing spatial data. This data can include digitised maps of various graphic formats as well as textual and numerical tabular data in the form of database files.

One of the key technical strengths, at least for this research, is the way that ArcView keeps track of all data in a single project file. The information in this file is in the form of text rather than a binary file and, thus, can be edited manually by the user. This is useful because at certain times during this research the location of much of the GIS data changed and by simply editing the project file, these changes were accounted for and the project was not detrimentally affected. Part of this portability is due to this version of ArcView being able to handle relative path names, that is, directory locations with no corresponding drive designation, for example, the standard way of describing where a particular resource is located on PCs is the path name, which can either be absolute, as in-

F:\programs\graphics\ESRI\AV_GIS30\ARCVIEW\BIN32

Or it can be relative, as in-

\programs\graphics\ESRI\AV_GIS30\ARCVIEW\BIN32

This inclusion of drives letters on all computers running the Windows operating system can cause major problems if the software is moved to a drive using a different letter, as can be the case, if the research data and software is transferred to a different computer, which unfortunately occurred several times during this research. This is, of course, not an issue on UNIX based systems such as, for example, Linux, Mac OSX which do not use drives letters. The Quantum Geographical Information System (QGIS), an open source computer program based on the GRASS system is equally portable and user friendly, though its evolution of utility has come too late to be of service in this research. There are many other useful features of ArcView, most of which can be read about elsewhere. Some researchers, in fact, have created predictive models solely using ESRI products (Allen 2000:107). However, given the availability of higher quality and more appropriate tools, it has been more beneficial not to limit the research to a single application.

In this research acquisition of above surface imagery is deemed to be of some importance in locating possible Harappan port sites. To recap, an attempt, has been made to accumulate, on a gradually increasing scale of resolution, various data.. It has been initially hoped that these data will prove to be particularly useful in identifying new sites, much in the same way as city of Ubar has been located through use of remote sensed satellite imagery by the Fiennes expedition a decade earlier (Fiennes 1992). Therefore, the subject now turns to how the various data sources retrieved earlier have been processed into a state useful for GIS analysis within ArcView.

Adding Database Data to ArcView

In order to place the chosen sites as a theme or graphical overlay on top of the maps of the Gujarat in the GIS, a source of map coordinates is needed. The data is taken from the Possehl Gazetteer and the Thakker ports project data described earlier. The latter source provides some unconfirmed data of possible port site locations identified through satellite remote sensing imagery data and the former adds substantial data concerning these sites. These tabular data sources include contain latitude and longitude data in degrees, minutes and seconds of arc that have been converted to decimal coordinates using a computer program designed in this research for various unit conversions (Appendices: conversi.bas). The decimal values that result in this conversion are then used to add a points theme to the GIS model by first building a database consisting of a comma separated values (.csv) plain text file. This text file is then linked to ArcView. The fact that ArcView can use comma separated values files has been of great benefit when constructing the predictive model as no further conversion from a proprietary database format has been necessary. With this ArcView theme installed, possible port sites can now be seen highlighted and superimposed over the landscape of the Gujarat. The raw data itself, such as coordinate and place name for each site is also viewable by the user. By attaching this data file to ArcView, the first steps in designing the predictive model are taking place with the organisation of data into an evolving database or "geodatabase" (Conolly and Lake 2006: 54) that will form part of the site location model.

Adding ESRI Themes to ArcView

Adding these data sources obtained from the same company that also produces the GIS is, unsurprisingly, quite simple. The themes, once added as layers, displayed highly contrasted features in bright colours, for example, rivers and water bodies are depicted in bright blue.

Adding Remote Sensing Data to ArcView

What follows, is a brief, description of how satellite graphical imagery data has been incorporated into ArcView. Notice should be taken that the methods used here will, almost certainly, differ greatly than those used in other projects depending on the particular GIS application used. In any event, the ArcView application is started and a new view created and named, in this case-

The Gujarat at 250m Res + Various Layers

All the collected images are then properly georeferenced, if not already in the form of pre-referenced files, such as geotiffs. To surmise, georeferencing means that imagery data is placed at this scaled within the context of real geographical coordinates. In order to accomplish this in ArcView, using picture file formats such as jpegs, for each jpeg image, a corresponding ArcView world file, plain text file with the ".jpw" file extension must be created. These contain the longitude latitude of each corner of the image as well as the amount of skew (Kerski 2004). Then when the pair of files are loaded into ArcView, the image is automatically fitted to the underlying map projection system.

Finally, by introducing buffer themes in ArcView it has been possible to experiment with different ranges. For example, in order to facilitate a general estimation of possible extents of economic and administrative influence of each site in the database, from a purely graphical point of view, in ArcView, buffer themes (Ormsby et al 2001: 297) have been created around each port site at ten, twenty and thirty kilometre intervals. Any intervals much smaller than this and the sites are completely isolated, whereas at much higher

intervals, the circular zones become all encompassing. These themes take the visual form of circles surrounding points representing a site location.

Therefore, to surmise the role of ArcView in this research, it is fair to state that ArcView is utilised here as the main GIS component of this research because it is easy to use and install, interfaces effectively with the database aspects, that is, the plain text, comma separated files containing the ports of interest that can subsequently be used in formulating the basis for a gradually developing dataset that will assist in eventually creating a site location predictive model later in this research.

The following figure overleaf shows the GIS created for this research (Appendices: gis.zip) with the following layers visible- twenty kilometre buffers and a satellite photograph.

Figure 5.3 ArcView GIS: Harappan Port Sites in Gujarat

Regarding these buffer-zones, it is worthwhile to note the thoughts of Greene on the matter. He believes that landscape archaeology is inseparably connected with environmental archaeology and if a 'systems theory' approach is used, and assuming free-will of the inhabitants, the location of a settlement is more probable in an area where the inhabitants have the easiest access to resources and this is the basis of site catchment analysis where an arbitrary line is drawn around a site to determine resources that may lie within, for example, walking distance; though artificial and not taking into account terrain, it does allow a better understanding of the potential of a site, standardised units, such as ten kilometre circles can be used (Greene 1995: 52). However, he goes on to say that catchment analysis is open to the same criticisms that are levelled at systems theory and processual archaeology because it assumes a purely physical relationship between the people and their environment (Greene 1995: 53).

5.7.2 Paint Shop Pro

A map of the shoreline proposed in the paper by Gaur and Vora (Gaur and Vora 1999:5) has been digitally photographed and then exported to the Paint Shop Pro graphics manipulation program. A layer containing the port sites as points on a plain background has also been exported from ArcView. Both these layers have then been merged in Paint Shop Pro to form a new single image showing the sites superimposed onto the proposed coast line for later evaluation. The end result of this work is a map showing all the "port" sites of the Gujarat, in geographical relation to this proposed coast line.

Summary

In this chapter, the pre-requisites of the model are discussed in detail.

This consists of describing the sources of data, attributes tools and the creation of the GIS. The attributes selected include environmental features, cultural phases, site typology, previous field work and a set of calculations to determine pattern and density of the distribution of sites within the landscape.

Also included in this chapter is a review of software required in order to build the model and the technological concepts involved in building the model.

The construction of the GIS has also been described in detail.

Conclusion

Now that the data has been collected, attributes chosen and tools selected, the next chapter will be an examination of all parts of the modelling process culminating in a predictive model ready to be used in this research.

6 The Harappan Ports Project Predictive Model (HPPM): Construction

From what has been learned during the course of this research, it is now possible, at least in prototype form, to construct the Harappan Ports Project Predictive Model (HPPPM) as a deployable predictive model for site location of Harappan age ports in the Gujarat. Thus, what follows is a description of the model construction process.

The format of this chapter can be described as a sub-project following the simple guidelines for documentation set forth in a template for student projects in software engineering (Delaney and Brown 2002).

As archaeological research falls into the category of social science, an effort has been made to tackle this study from an archaeological standpoint rather than that of a software development project. This approach has both advantages and disadvantages. The main advantage is that the end product, that is, this thesis, is specifically targeted to be accessible to a social science readership. The greatest disadvantage is that, as a result of this, the software development documentation is non-standard and sparse as compared to a traditional software project (Delaney and Brown 2002). It is hoped that this situation that is somewhat remedied in this section where each standardised documentation deliverable (Delaney and Brown 2002: 2) has been produced, at least in brief form so as to produce sufficiently informative project documentation.

Given that this is a small and rapid software development project in social science, the overall documentation will be far smaller in quantity than a larger information systems project. It is also hoped that what is revealed during this phase of the research will enable ideas to be formed in the consideration of further research such as the possible future development of a generic "off-the shelf" predictive model.

6.1 Software Project Management Plan

6.1.1 Introduction

Project Overview

The overall aim is to construct a first functional prototype of the HPPPM. In broad terms, this model construction sub-project consist of three tasks divided up into smaller sub-tasks. The tasks consist of the production of a database component, a pattern matching component and a distribution analysis component. Each of these components must undergo the sub-tasks of design, development and testing.

Project Deliverables

The sub-project is deemed to be complete when a working prototype is tested and concise documentation produced, including commented code, an over-all diagram, that is, a flow-chart describing a high-level view of the model.

6.1.2 Project Organisation

Software Process Model

Thus, a general over view of the processes involved can be seen overleaf.

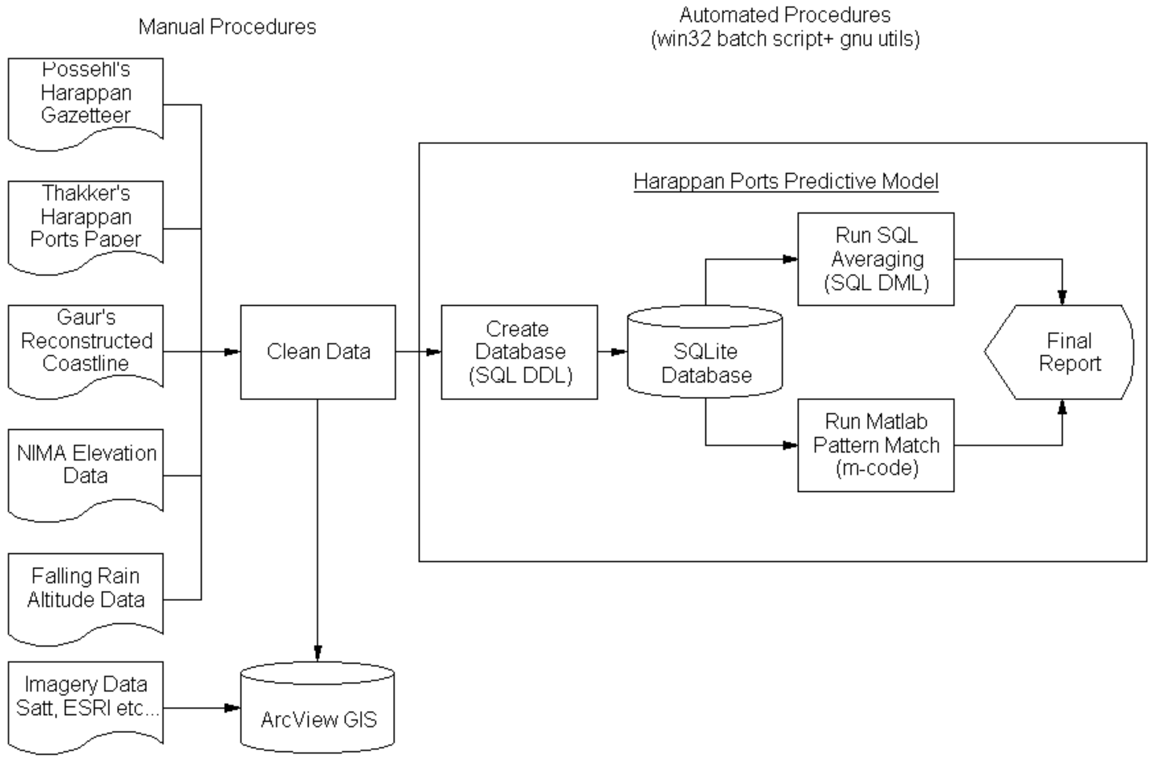


Figure 6.1 Predictive Model Flow Chart

It should be noted from the diagram, that unlike many archaeological predictive models (Espa et al 2006: 147), apart from the shared data, the predictive model is not based within the GIS itself. Although it is, of course, acknowledged that GIS specific software such as ArcView is capable of some complex processing of data, such as the work of Hansen with spatial statistics (Hansen 2000), after a thorough review of software (see Software Review 5.5) other database tools have been found to be far more effective than those available within the standard GIS software.

Roles and Responsibilities

There is only one researcher responsible for producing this sub-project, user interviews may be deemed necessary in developing later, more generic models, but for the HPPPM, requirements are fairly domain specific.

Tools and Techniques

For the purposes of documentation, this sub-project follows a simplified format for software engineering.

In terms of development life-cycle, a rapid, iterative design, development and test cycle is followed.

A variety of programming languages are used- win32 batch, SQL, UNIX shell scripts and Matlab m-code.

Tools used include SQLite, GNU file and text utilities for win32, Matlab and FreeMat.

6.1.3 Project Management Plan

Tasks

Produce Database Component

The SQLite software is used to store data and formulate queries. The data consists of all the material gathered thus far (see Appendix A: harappan.csv).

Produce Pattern Matching Component

This consists of a Matlab m-code program developed in Matlab and later transferred to FreeMat.

Produce Distribution Analysis Component

This is simply a continuation of the above program.

Note, that all components are dependent of one another so that the whole will function and, given the limited time available, only the core functions are deemed to be critical and factors such as the design of a GUI interface are thought secondary at this stage.

6.1.4 Time Table

A time table in the form of a miniature Gantt chart is included overleaf.

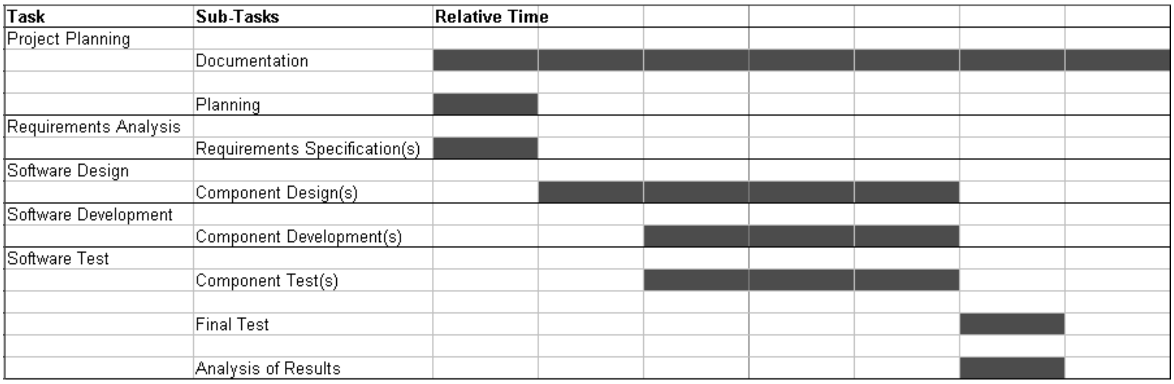


Figure 6.2 HPPPM Time Table Gantt Chart

6.2 Software Requirements Specification

6.2.1 Introduction

Product Overview

A description of the requirement for each component of the model now follows.

Requirement for Database Component

The requirement here is to find a format in which to both store and access the data collected from various sources over the course of this research and to also develop all the associated code necessary to run the model. The format needs to be simple, fast and portable, that is, usable on many operating system platform.

Requirement for Pattern Matching Component

Pattern analysis is required in terms of post-processing of the data from the database component. This component needs to store longitude and latitude decimal coordinates in a way that can be passed on to the Distribution Analysis Component.

Requirement for Distribution Analysis Component

The Distribution Analysis Component should use the data from the Pattern Matching Component to analyse the distribution of sites in terms of comparative percentage values.

6.2.2 Specific Requirements

Interface Requirements

User Interfaces

In terms of user-interface, given that this is only a functional prototype, there is no custom made user interface. Data entry and query is either via raw SQL language within a database command shell or by use of a third part GUI interface.

Hardware Interfaces

As described before (see 5.5.10) the model runs on standard PC equipment.

Software Interfaces

The model currently runs on most win32 operating systems- Windows 2000/XP/Vista (see 5.5.7).

Communications Protocols

Internally, each component communicates with the other by first completing its specific task and then producing output files which are then accessed by the next component. All the components are controlled from a single main script written in win32 batch language using cmd.exe and UNIX shell tools. Externally, the final report is automatically outputted to the user in the form of a formatted text file.

Software Product Features

Once the data is entered into the database, the entire process is autonomous and requires no further user input, other than the user initiating the model via a single instruction from the command line.

Software System Attributes

Reliability

The model is deemed reliable, if each component successfully communicates its output to the other and a final report is produced.

Availability

The model is available to run on an ad hoc basis, requiring no particular user privileges at this stage as the application is a single-user database with no concurrency or database row locking capability other than what is available by default in SQLite.

Maintainability

Given the relatively small dataset of less than three thousand rows, the goal is for zero maintenance. Should a generic, non-Harappan specific version be developed in future, there will be even fewer rows. This small size also means that, at present, a customised solution for the reduction of white space in order to facilitate data compression and, thus, reduce the size of the database is currently thought unnecessary. Other issues may require further consideration in future though, such as the need to, perhaps, compile some of the code, field validation and general user-proofing.

Portability

The model is at present almost completely portable. It is already deployable without installation on any win32 operating system platform. Most of the model, with minimal effort can also be deployed on other platforms such as Linux due to the availability of the software used in the model on other platforms. For example, FreeMat is available on win32, Linux and Mac OS X (Basu et al 2009) as is SQLite and most of the core tools.

Performance

The model should not take more than five to ten minutes to run and, in fact, the final model takes approximately ten seconds for completion.

Database Requirements

A simple, non-server type portable database that is easy to deploy is required. SQLite fulfils this requirement.

6.4 Software Design Specification

6.4.1 Introduction

Design Overview

A description of the design of each component is now given.

Design of Database Component

A by-product of the GIS component of this research is a table of possible coastal sites and riverine ports in the Gujarat has now been compiled. The data is gathered from the Harappan ports project of the Indian Space Agency (Thakker et al 2000) and the Possehl Gazetteer of Harappan sites (Possehl 1999: 727-845) as well as many other documentary sources. Physically, the table can be described as a comma separated plain text file. In the GIS model this is used to supply site location points on the various ArcView map layers of the region. By constantly adding to this table through further research, it is now the data source and the basis of all other software components of the predictive model.

Given the low-performance requirements in this research, SQLite has been selected as the RDBMS of choice. To summarise, SQLite has been chosen over other products because it

is open source and free, fast and reliable in both installation and use in comparison to industry standard databases such as Oracle that tend to be notoriously difficult to install, configure and are grossly over-powered for an application of this scale.

The design of the database is quite simple as there are no repeating groups of data. In lay-terms this means that for each row in the separate tables from Possehl, Thakker and the data gathered during this research, there is only a one-to-one relationship. That is, each site contains one row of corresponding data. This means that it is necessary to create one database containing a single, albeit large, table.

To concatenate all this complex, voluminous and disorganised data, however, is not a simple task. Here the challenges include cleaning and collating the data into a form that is usable by the SQLite database. This process of data cleaning has been accomplished by using the GNU file and text utilities for Win32, Open Office calc- a spread sheet program similar to Microsoft Excel and the VIM text editor. The GNU utilities such as grep, sed and cut and the text editor enables the searching, sorting and reconfiguring of the data, while calc allows the data to be rearranged and saved as a comma delimited text file. This has been attempting using standard Microsoft tools such as Excel, however for some as yet unknown reason, the comma delimited text files produced by saving from Microsoft Excel seems to be incompatible with the procedures for importing data into SQLite. This may concern the file format differences between files saved in Windows systems and those saved in UNIX as a similar problem has been revealed from results returned from SQLite. In short, it is simpler to work with tools originally designed for a particular operating system, in this case UNIX.

Design of the Pattern Matching Component

After considerable difficulties in attempting to create a program for pattern matching in a geographical context, and all the difficulties that entails and as a result of consulting other graduate researchers, Matlab (Math Works 2007) has been revealed to extremely useful for these tasks as well as the post processing of this data. The computer technology/archaeological science interface, thus emerges and, though this can be seen in many parts of the research, it seems most clear in this pattern recognition component of the

predictive model program that processes data to feed to the next part of the program dealing with site distribution.

The only data input need for the Matlab program to function are the geographical latitudinal and longitudinal coordinates of each port sites and these are provided for in Thakker's tabulated data. The Matlab software contains all that is needed to develop the program within its own environment. The only major design criteria is that the program, once created should be able to run in "batch", mode, that is, non-interactively or automatically when called from the main should be program. The function is available in Matlab via the "-nosplash -nodesktop -r" command line options. The ability to run everything automatically without further user input has speeded the design-development-test cycle considerably as running a program in Matlab batch-mode requires much less system overheads in terms of memory and processor usage. One problem, however, that has had to be solved is that the main program, in this case a Win32 batch file, from which the SQL and Matlab programs are run will not wait for the Matlab component to be finished before writing results to a final report. Usually this is solved by some simple batch scripting using the "start /wait" command available in Win32 operating systems. However the Matlab program seems immune to this type of exterior control. Therefore, a simple UNIX command "sleep 5", using the GNU sleep utility, is used in the main program to wait five seconds for the Matlab component to finish before continuing to the next stage.

<u>Design of Distribution Analysis Component</u>

As a result of creating the pattern matching program in Matlab, it has been possible to use the outputs as area distribution pair percentages in some further tests.

Because the distribution values are produced in the pattern matching program, all that is required to add these additional distribution analysis algorithms is to incorporate some extra code into the Matlab program. Therefore, immediately after the Matlab program produces the distribution values, it continues to carry out this extra processing, prior to outputting all final results of the data to an external file.

6.5 Software Devlopement

6.5.1 Introduction

<u>Development Overview</u>

A description of the development of each component follows.

6.5.2 Development

<u>Development of the Database Component</u>

Now that all data attributes for use in our model have been identified, selected and collected throughout the research effort, that is, following on from the work described in previous sections, they must be collated into a single table prior to further processing. In total there are one hundred and thirty seven data fields or columns of data in the database far too numerous to describe in detail here. The pertinent facts are that the fields are assembled from the Possehl Gazetteer, the Thakker tabulated results as well as data from other sources described earlier. Not all the fields in the complete database are actually used for the predictive model as much of it relates to the Harappan culture as whole and not specific to the possible maritime sites in the Gujarat.

The first step is to create a program for sending instructions to SQLite, to load all accumulated records from the data file, into a database that can then be queried in order to retrieve data useful for site location and to answer the question of what is a Harappan port. In other words, this is the process by which the raw data is sifted and filtered to extract information useful to this research. To accomplish this a script or program containing coded instructions has been created. This is a program with several stages.

The first stage creates an SQLite3 format database with a table. Though the table matches exactly the structure of the data file, it is thus far, completely empty. Now the program

loads the data from the data file. In terms of performance, two thousand and nine hundred records, each containing one hundred and thirty seven columns are loaded in approximately one second.

The second stage is a little more complicated. Here rows of data are not simply retrieved as this would serve no purpose to the model. The objective here, at least at this stage, is to combine all of that is known Harappan port sites into one average site by combining all the rows into one single row. However, there are several problems with this approach.

First, the rows and columns obtained from the Possehl spreadsheet, far exceed the data obtained from the Thakker research as well the search for data conducted during this research. There are, in fact many columns of data that have no relevance to this project. For example, columns that refer to other geographical areas outside the Gujarat. In order to resolve these problems, the power of SQL language is utilised. This is accomplished by first referencing only the list of proposed ports in the Thakker table as the basis by which all the other rows will be matched. Without going to unnecessary technicalities, if possible, this is achieved by stating in the code that all rows must be retrieved only where a port site identified by Thakker exists.

The second obstacle to overcome concerns finding a method of returning an average value from a text field. For example, to find out if, on average, most sites do or do not show the presence of characteristic red polished ware. Because the data contained in this field is either "TRUE" or "FALSE" a simple numerical average will not be possible. Instead an SQL algorithm must be formulated. This is where some limitations of the SQLite version of SQL syntax are revealed. To do this in other SQL dialects, there is a function called TOP, that can be used. Here, however, since this is not available, another option is sought. The answer comes in using the SQL function LIMIT, used in a slightly unorthodox manner to produce the same result, that is, to limit data returned from the query to the most common text in that particular field. Therefore if, for example, there are three instances of "TRUE" and only one of "FALSE", "TRUE" is the result returned as the most common field. There is are certain problems with the function that should be mentioned; if there are equal numbers of the same data, for example, two attributes containing the value "TRUE" and two containing the value "FALSE", then the function becomes unpredictable and may

pick either. This is only a limitation when there are only a few rows present in the rows retrieved. A simple explanation in terms of statistics is that the average string value is actually the value that occurs the greatest number of times, in other words, the mode (Caswell 1982: 26).

The final problem concerns numerical averages. The problem is that the average function in SQL works by counting the number of rows returned in order to calculate the number to divide by. This is satisfactory as long as there is a value in that row, but what happens for rows that have no value? These are still counted. For this reason, conditions are set in the SQL program code, in the form of a clause that states that only rows that actually contain a value are to be returned and then subsequently used in calculations of average.

Thus, through the methods described above, and in the nomenclature of relational databases, an SQL query is created that can retrieve the data. The retrieved data is then sent to an external file.

The results and analysis of the data returned from this query, that is, the final output, will be examined in another section.

A flow diagram describing the process from the point of view of the life-span of a single variable has been included overleaf to simplify the above explanation.

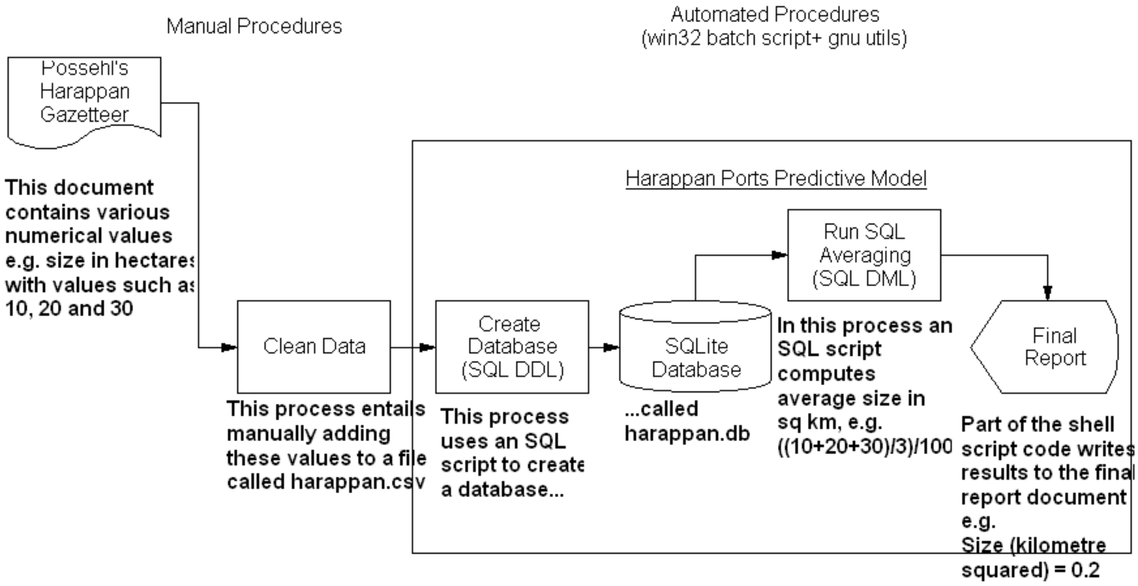


Figure 6.3 Life-Span of One Database Variable in Predictive Model

Development of the Pattern Matching Component

The same geographical latitudes and longitudes for each of the Thakker port sites in decimal degrees that are used in the GIS, also become elements of the arrays, or matrices in Matlab terminology, called X and Y in the Matlab m code script. Thus, each extreme geographical extent of the coordinate pairs are then calculated by program code that searches for the highest and lowest numbers. Mid-points are also calculated in order to mask off the whole area into half sections, such as north and south, east and west. The same is done for the core or centre area of the map contrasted with the surrounding periphery area by identifying the quarter-points. When this is done, each port can, thus, be isolated and counted within the program to calculate how many sites are split between each section, for example, how many port sites are split between north and south of the mid point. This ratio is then calculated as a percentage. The same procedure is carried out for each of the other split sections. In effect, this is actually quite similar to a simple Optical Character Recognition (OCR) program that scans the images of text characters and returns a value based on a match of stored characteristics of each letter, though it should be noted that this component of the HPPPM is far less complex that true OCR software as the only requirement here is to count single objects, that is, points on a map. It is not a pattern matching tool in tradition of machine learning (Theodoridis and Koutoumbas 2006: 1). The flow diagram overleaf describes this process.

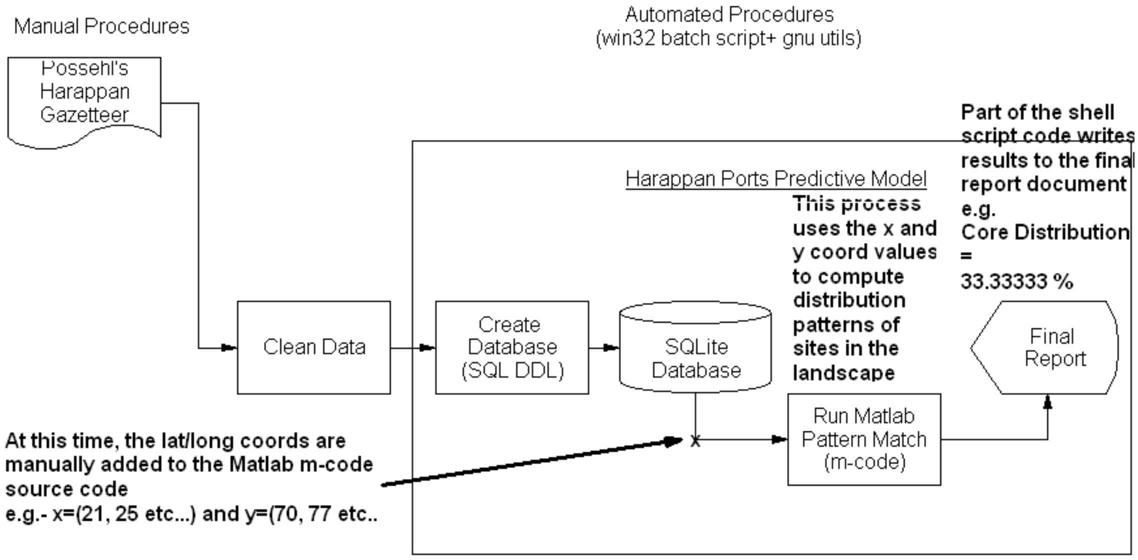


Figure 6.4 Life-Span of One Matlab Variable in Predictive Model

The distribution data is then sent to an external file, the results and analysis of which are the subject of a later section of this research.

<u>Development of the Distribution Analysis Component</u>

This is a continuation of the above Matlab code where the program now takes the percentage distribution within the core area and calculates how close it matches the periphery area. This will return a value of how evenly distributed the sites are across the entire geographical extents, that is, how uniform the sites are on a geometric plane, similar to the assumptions made with Central Place Theory.

Another test of site distribution in the landscape concerns how clumped together the sites are. This idea is a "Nearest Neighbour" (Barcelona Field Studies Centre 2008) type test and looks for patterns such as clustering by comparing the distribution between north and south areas and east and west areas. Higher differentials between split areas indicate greater clustering. Both of the above tests allow a leeway of approximately ten percent in order that significant trends may be identified.

The distribution data is then sent to an external file for compilation into a report.

6.5.3 User Interface

<u>Description of User Interface</u>

From the aforesaid requirements the user interface is to be basic and assist in the overall development and testing of the model, thus the choices made here are based on simplicity and utility. There is no GUI design per se, just a brief investigation that entails locating a "bolt-on" product in the shape of SQLite Browser and Open Office Calc that can allow simple data entry. Once the model is set in motion a report is automatically generated for the user. An image taken from the screen shows the model with its associated data entry tools and output report overleaf.

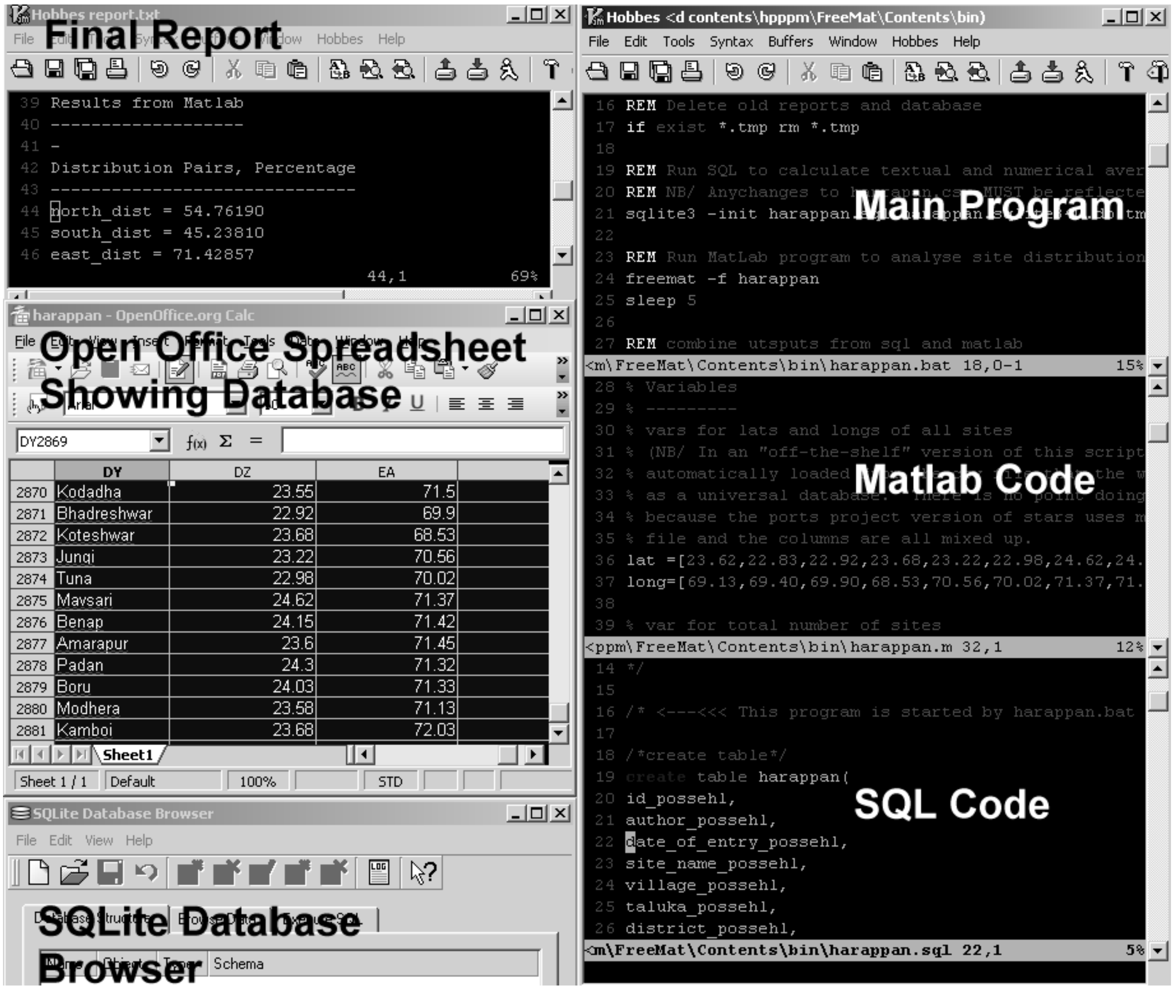


Figure 6.5 Screen Image of Interfaces and Outputs

6.6 Software Test Documentation

6.6.1 Introduction

The purpose of the testing is not only to ensure that the program as a whole is functional. This is misleading as production of a report only implies that the final component is able to output data. It is important therefore to check the outputs of each component as well as the communication linkages between them. There is also a need to test the final results of the model to see whether the model is producing reports of sufficient quality to be archaeologically useful in discovering location criteria for port sites in the Gujarat.

6.6.2 Test Plan

<u>Features to be Tested</u>

The plan therefore is to test each component individually, then the program as a whole and finally the data outputs of the program, that is, the final report.

<u>Features not to be Tested</u>

As this is a prototype system features such as end user satisfaction indexes, GUI eventing test and field validation are not considered a priority as the aim is not to produce a production system at this stage.

<u>Testing Tools and Environment</u>

The testing will take place in the same environment that is used for development and design except that frequent back-ups of individual files and copying the entire research directory to an external hard disk once daily will be instituted as a routine procedure. In technical terms this means version control and mirroring procedures will be instituted.

Inputs

The inputs, in order of use, are inputs of the data from the comma separated file that the SQLite scripts use as a source of queries; the results of which are then used as inputs for the final report as is the data output from the Matlab program.

Expected Outputs & Pass/Fail criteria

The expected outputs are those generated by each component and the final report, which, if after testing for accuracy, does not contain a logical output, that is, it is not able to accurately predict the criteria for a port site in the Gujarat it will be deemed to have failed. Accuracy will be judged sufficient with a match in excess of fifty percent.

Test Procedure

This stage proceeds with a step by step testing of each component.

6.6.3 Test

Testing the Database Component

Testing the software, as can seen where testing of other components has been explained, testing has proven to be the most demanding and laborious of all the tasks in this sub-project of the research initiative. Several important pit-falls have been avoided due to thorough testing, not only of the software, but the integrity of the results. To test the database components, it has been necessary to manually the count rows returned in each query. Without these testing procedures, the particular manner in which numerical averages are calculated in RDBMS would have gone unnoticed and the results returned inaccurate.

There has been an attempt during the early stages of the development of the averaging procedures to include a function whereby skewness and kurtosis may be identified and median values selected in preference. After some research, it has become apparent that there is are different formulaic methods for calculating these values and most mathematical software use different methods that actually produce different values, thus, this rather time-consuming effort has been abandoned. On reflection, this is not important as the main logic behind seeking skewness and kurtosis values are abnormal averages produced as a result of counting rows with null values in the calculations. Once this was solved, as described earlier; by not including null rows in calculations which can lead to abnormally low values, the requirement for this extra functionality was removed.

<u>Testing the Pattern Matching Component</u>

Again, testing the accuracy of the program has proved to extremely laborious. The only simple part to the testing is where the built-in GIS functions of Matlab have been utilised.

Thus, the first part of the testing requires a check that the Matlab software views the sites locations in the same way that the GIS views them. In order to test this, the GIS plotm function is used in Matlab. This is a variation of the plot function which is used for plotting points on a graph. The difference is that plotm will plot the points of a map using a specified geographical projection system; in this case the Mercator system. This projection is the best to use with this type of data because it avoids having to deal with the complexity of spherical distortion. Ignoring spherical distortion of the Earth is not such a contentious issue because the geographical range for these sites is not large. The output of the plotm function is a picture of red dots against a white background. The layer containing the sites locations is also exported from ArcView in the form of a bitmap image. These two graphic files are then inspected and compared for any differences. Since there are none, it has been proven that there is a consensus between both the Matlab program and the GIS data.

The second stage of the testing is to manually follow the exact procedures, aims and objectives of the Matlab program code. To this end the output from the GIS is imported into the graphics manipulation program Paint Shop Pro 5.03 (see 5.5.5 and 5.7.2). Each

stage of finding the geographical extents, dividing and quartering this area and then counting the sites has been reproduced manually. If all is well, then the dot counts, that represent sites, will be the same as those generated from the Matlab program for each sub-divided section. Subsequently, this has proved to be the case. The image used in this manual test also serves as a useful guide to the pattern matching process and thus, is included overleaf.

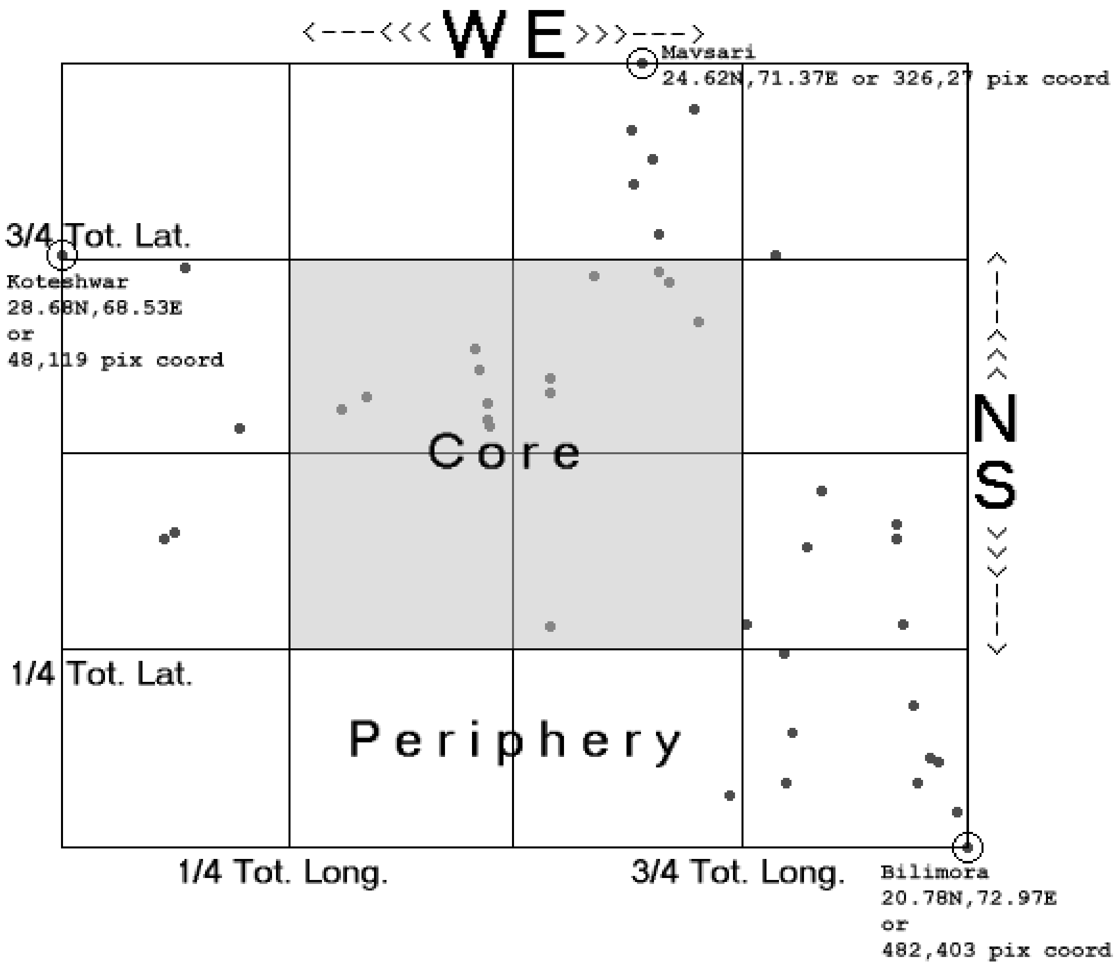


Figure 6.6 Pattern Matching Test

Testing the Distribution Analysis Component

Testing takes place using exactly the same method as previously described for distribution, that is, by manually counting the sites using the image in Figure 6.6 (see Figure 6.6 Pattern Matching Test).

6.6.3 Test Results and Analysis

Before the model is ready to be utilised, there is one additional task to be completed. That is to test the complete model in order to determine the efficiency and accuracy of its performance. However, without further fieldwork to reveal any new, as yet undiscovered sites sharing a similarity of features produced by the model and thereby confirming the validity of the model, a testing strategy must be formulated using the existing data. This testing procedure is now explained.

An obvious test of how well the model performs can be achieved by removing one of the existing sites from the database and its associated geographical coordinates from the pattern matching component of the HPPPM and then running the model again. The average site produced by the model can then be compared to this existing site without the results of the existing site introducing any favourable numerical bias. If the values match closely, then the model can be determined to be running with, at least, some degree of efficiency and if the values vary greatly then this indicates that the model may be flawed through either mathematical or logical error or simply a lack of data. Thus, as a way of ascertaining to what extent the values of the variables differ between the average site and an existing site, in this case Lothal, the following table of test results has been composed.

	Original Values		Converted to Numerical Values			
	Average Site	Lothal	Average Site	Lothal	Difference	Diff (%)
Environmental Features						
Nearer Gaur's Coastline Reconstruction	"No"	Yes	0	1	1	100
Elevation (metres)	7.875	9	7.875	9	1.125	12.5
Altitude (metres)	21.16666667	53	21.16666667	53	29.38	60.0628931
Cultural Phases						
Harappan	TRUE	TRUE	1	1	0	0
Early Harappan	FALSE	FALSE	0	0	0	0
Harappan Urban Phase	TRUE	TRUE	1	1	0	0
Harappan Post Urban	TRUE	TRUE	1	1	0	0
Kulli	FALSE	FALSE	0	0	0	0
Sorath Harappan	TRUE	FALSE	1	0	1	100
Jhukar	FALSE	FALSE	0	0	0	0
Late Sorath Harappan	FALSE	TRUE	0	1	1	100
Lustrous Red Ware	FALSE	FALSE	0	0	0	0
Late Harappan	TRUE	TRUE	1	1	0	0
Red Polished Ware	NULL	NULL	0	0	0	0
Site Typology						
Settlement	1	1	1	1	0	0
Cemetery	NULL	1	0	1	1	100
Size (kilometre squared)	0.0286666666666667	0.48	0.0286666666666667	0.48	0.4513333333333333	94.03
Field Work						
GPS	FALSE	TRUE	0	1	1	100
Excavated	1	1	1	1	0	0
Explored	NULL	NULL	0	0	0	0

Table 6.1 HPPPM Test

(Continues on next page)

	Original Values		Converted to Numerical Values			
Distribution Pairs, Percentage						
North Distribution	56.09756	is not located north	1	0	1	100
South Distribution	43.90244	is located south	0	1	1	100
East Distribution	70.73171	is located east	1	1	0	0
West Distribution	29.26829	not located west	0	0	0	0
Core Distribution	34.14634	not located at core	0	0	0	0
Periphery Distribution	65.85366	is located in periphery	1	1	0	0
Distribution Density						
Most Sites	east	is located east	1	1	0	0
Least Sites	west	is not located west	0	0	0	0

Table 6.1 HPPPM Test

(Continues on next page)

	Original Values		Converted to Numerical Values			
Geo-Soc-Pol Models, Probability						
CBT Uniformity	Probability Low	Probab ility Low	0	0	0	0
Nearest Neighbourliness	Probability Low	Probab ility Low	0	0	0	0
Average % Difference between Average Site and Lothal			**28.89**			
Average % Match between Average Site and Lothal (Model Accuracy)			**71.11**			

Table 6.1 HPPPM Test

It should be noted that for ease of calculation all text string values have now been converted to numerical values; "TRUE" has a value of one, "False" has value of zero. Also any NULL values are judged to have a value of zero and the percentage differences have been calculated using the following formula-

100 minus (Average Site divided by Existing Site) multiplied by 100

Statistical calculations such as standard deviation are not necessary as, for each variable, only two values are being compared.

Thus, it can be seen that the model runs with an overall accuracy of around seventy percent.

Regarding this score, Warren comments about a GIS that has been used to create a high resolution predictive model for prehistoric archaeological site locations in Illinois in the United States of America where testing has revealed the model to be seventy-three accurate, thus, he believes that the capabilities of the predictive model may be judged useful (Warren and Asch 2000: 7).

A simple graphical representation of these results can be seen in the following graph that plots the values of the various variables used in the model.

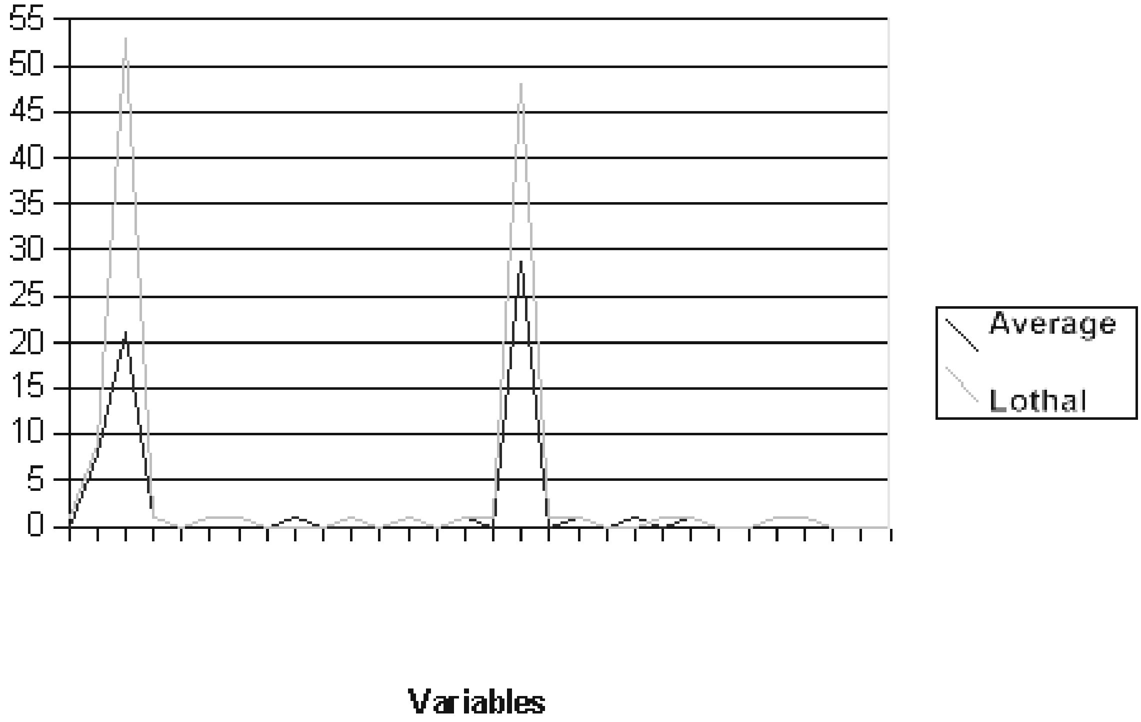


Figure 6.7 Average Site (Model) Compared to Real Site (Lothal)

As can be seen, on balance, the model results matches the "unknown" existing site of Lothal with fair degree of accuracy. Where Lothal shows the most marked difference, and hence the exaggerated spikes in the graph, are where Lothal differs in altitude and size from the average port, however, taken individually larger Harappan sites than Lothal exist.

The model, therefore should be considered sufficiently complete and ready to generate final results.

6.6 Summary

In this section all steps of the sub-project to design a predictive model to identify the criteria for port sites in the Gujarat have been described in detail. These steps include application planning, design, development and testing. To surmise, the predictive model described above, takes in raw data from a carefully assembled database file of data concerning the Harappan Civilisation. Then, a combination numerous algorithms and sub-functions formulated using various program scripts in various languages, interface with this file. Database retrieval scripts, pattern recognition algorithms and statistical tests are applied in order to find probable port sites based on commonality of criteria. This criteria adds to the usual environmental data by deriving results from the data based on conceptual premises from other disciplines. Finally, it has been found that the model reaches a favourable level of accuracy during the testing phase.

6.7 Conclusion

The HPPPM has been found to be sufficiently accurate and functional. Thus, the model can now be used for its intended purpose with a degree of confidence.

Regarding the use of simple statistics used in these calculations, it has been stated that much archaeology uses intuitive statements based on experience rather than calculation;

statements that involve comparisons these can be checked for accuracy using simple statistics and probability testing is appropriate in these cases (Shennan 1988: 155, Fletcher and Lock 1991: 155).

Finally, to reiterate, the aim of the model is to identify criteria that may assist in identifying possible Harappan port sites, thus in the following chapter the resultant output of the model will be explained, an analysis offered and conclusions drawn.

7 The Harappan Ports Project Predictive Model: Post-Construction

7.1 Introduction

A brief recapitulation regarding the basic premise, methodology and structure of the model is now offered prior to an analytical look at the results and a critique of the model.

It has been mentioned throughout this research that much discussion has been made on the subject of environmental versus social, political, economic and other factors with the majority of models following an environmental bias (Brandt et al 1992: 269). Thus, the premise of this model, due to a general lack of readily available environmental data, attempts to utilise every available data source and methodological approach applicable, time and research resources permitting, including both environmental information and theoretically derived techniques in order to maximise a limited data set and to test the validity of existing research.

Concerning the structure of the model, by referring back to Figure 6.1 (see Figure 6.1 Predictive Model Flow Chart), it can be seen that the entire research procedure has involved the collection and assemblage of data for both the GIS and predictive modelling streams of the research. Compiling a set of clean data and building the GIS is a manual process, while running the predictive model fully automated and autonomous. The predictive model consists of several scripts or programs in different programming

languages- SQL, Matlab, shell script and batch language. These scripts access the data, collected and cleaned and, through the previously described process, create a final report ready for analysis.

7.2 Running The Model

Thus, all of the research concerning, data collection, model building, testing is finally complete and the application is now ready for implementation. The implementation of the model is simple. In order to generate the final results, the values for Lothal that were previously removed for testing purposes are now returned to the database and the predictive model is then run again. In order to do this, at the win32 command prompt the script name harappan.bat is typed and the enter key pressed; what follows is completely automated and results in a file called report.txt which can be seen in Table 7.1 (see Table 7.1 HPPPM Results).

Environmental Features	
Nearer Gaur's Coastline Reconstruction	"No"
Elevation (metres)	7.941176
Altitude (metres)	23.61538
Cultural Phases	
Harappan	1
Early Harappan	0
Harappan Urban Phase	1
Harappan Post Urban	1
Kulli	0
Sorath Harappan	1
Jhukar	0
Late Sorath Harappan	0
Lustrous Red Ware	0
Late Harappan	1
Red Polished Ware	NULL
Site Typology	
Settlement	1
Cemetery	NULL
Size (kilometre squared)	0.0335
Field Work	
GPS	0
Excavated	1
Explored	
Distribution Pairs, Percentage	
North Distribution	54.7619
South Distribution	45.2381
East Distribution	71.42857
West Distribution	28.57143
Core Distribution	33.33333
Periphery Distribution	66.66667
Distribution Density	
Most Sites	east
Least Sites	west
Geo-Soc-Pol Models, Probability	
CPT Uniformity	Probability Low
Nearest Neighbourliness	Probability Low

Table 7.1 HPPPM Results

7.3 Analysis

Thus, the following is an interpretation of the final results shown in Table 7.1. It should be noted, as stated before, that values equating to "NULL", "0" and " " can be ignored as they amount to the same thing; they are a result of slightly inconsistent data validation from the third party data sources. In an ideal database, purpose-built from the ground up as a storage medium for a predictive model, data can be validated either through manual data checking procedures, or through some automated process. In fact, the point has already been made, in relation to using computers for the recording of archaeological data, that a well designed computer system can contribute by adding rigour and discipline by enforcing good and efficient practices on users entering data and that such advantages in using computers are not matched by paper systems and manual procedures (Eiteljorg and Limp 2008: 17). Though these zero values are ignorable in themselves, the reasons may sometimes be significant or, at least, informative and, therefore, an explanation may be offered. Also the results, where appropriate, have been grouped, additionally, they may be further sub-grouped where it is logical to explain a result in terms of a paired value, for example, in the case of the north-west distribution pair. The results themselves are raw and entirely unaltered and appear exactly as they do in the report generated by the model tabulated in Table 7.1 so as to demonstrate transparency of process.

7.3.1 Environmental Features

<u>"nearer_gaurs_coastline_reconstruct = "No""</u>

This has implications for the accuracy of the Gaur and Vora's original research (Gaur and Vora 1999). Taking into account minor errors of digital translation, the GIS and graphical superimposition makes it possible to see that their coast line (see Figure 5.1 Possible Port Sites in the Gujarat [note the dashed lines are the Gaur and Vora reconstruction]) seem to place some sites, such as Luna Mandvi, Bhadreshwar and Tuna nearer the coast at the expense of placing some current sites underwater, for example Kanakpur, Mahua and

Padri. The model, therefore predicts that any search for new sites need not include search areas near to the Gaur and Vora reconstruction because at present their results seem flawed.

<u>"average_elevation_meter = 7.94117647058824" and "average_altitude_meter = 23.6153846153846"</u>

Neither elevation (National Geospatial-Intelligence Agency 2009) nor altitude (Falling Rain 2009) are particularly relevant for site location in the model because the entire region is low-lying (Rao 1979: 3) and fairly uniform. Hence, Z-axis height values for sites are not included in further prediction calculations. For sites where height data exists altitude ranges between 7 metres at Khambat and 53 metres at Lothal (see Table 6.1 HPPPM Test), elevations remain in the range of 0 to 9 metres.

7.3.2 Cultural Phases

For clarity, it is advised to refer back to Figure 2.1 (see Figure 2.1 Harappan Chronology).

<u>"harappan = TRUE"</u>

"True" is the is equivalent to "Yes" or "1" and obviously, as all sites in our study are of Harappan origin and the purpose is to locating additional Harappan sites, this value is redundant and included only as a safe-guard because it, like some other redundant fields, is non-empty in the database and also to confirm that no non-Harappan sites have been inadvertently included prior to the averaging calculation.

<u>"early_harappan = FALSE"</u>

"False" is equivalent to "No" or "0" and this indicates that it is unlikely that early Harappan era sites will be found. This is because the early Harappan period, for example, the Kot Diji period at Harappa, spans around two hundred years; from 2800 BC to 2600 BC (Kenoyer 1997: Table 1), whereas Harappan development in the Gujarat begins at around 2400 BC or Period 3B (Mulchandani 1998, Kenoyer 1997: Table 1).

"harappan_urban_phase = TRUE"

The Harappan Early, Middle and Late Mature or Urban Phases spans the time period roughly from 2600 BC to 1800 BC (Kenoyer 1997: Table 1). Thus, these results indicate the beginnings of Harappan occupation in the Gujarat at 2400 BC (Mulchandani 1998) with Lothal developed in the Late Harappan Phase at around 2010 BC (Rao 1979: 39). Hence, potential sites will most lately be dated from c.2400 BC, for example, by radiocarbon dating of carbonaceous prospected artefacts. Of course, this being archaeology, one must allow for the possibility that a new discovery may change the chronology of the Harappan occupation of the Gujarat.

"harappan_post_urban_phase = TRUE"

With a slight overlap at c.1800 BC, the Harappan age ends at around 1900 BC to 1500 BC. For example, the town of Lothal is diminishes in importance from c.1865 BC to c.1555 BC, thus there is now a workable date range available for radiocarbon dating for Harappan sites in the Gujarat sites ranging from approximately 2400 BC to 1500 BC.

"kulli = FALSE"

This value, not surprisingly is "False" as it is the probable upland expression of the Harappan culture, or even an independent culture, in a different geographical region (Possehl 1999: 104), for example, the Kulli-Complex site at Kolwa in south Balochistan occupied around 2500 BC to 2000 BC (Mortazavi 2005: 110).

"sorath_harappan = TRUE"

This attribute indicates that the Sorath Harappan culture is the average type of site represented in the Gujarat at sites such as Rojdi (Possehl 2002: 60). This confirms mathematically what is already known in the archaeology; that is a distinctive regional variation of the Harappan culture in the Gujarat (Possehl 1997: 450). It is different in its greater emphasis on maritime activities and pottery (Possehl 2002: 60, Kapoor 2004) and

sometimes thought of as separate from the mainstream Harappan culture (Kapoor 2004). The Thakker port site of Kuntasi (Thakker et al 2000) is also thought to be of this type (Possehl 1997: 455). Regarding dates, it is a sub-phase of the Mature or Urban Harappan Phase (Possehl 1999: 18) dating from either 2350 BC (Herman 1996: 77) or 2500 BC to 1900 BC (Possehl 1999: 23). It is significant in that it demonstrates that it is more likely that new sites are to be found of this type in the Gujarat.

<u>"jhukar = FALSE"</u>

Again, this value confirms that mistakes have not been made, by selecting only Harappan sites in theGujarat, as this attribute refers to a short one hundred year phase, 1900 BC to 1800 BC at the site of Jhukar twenty-five kilometres north of Mohenjo daro (Possehl 1999: 18, 23, 84) and thus has nothing to offer in predicting sites in the Gujarat.

<u>"late_sorath_harappan = FALSE"</u>

This is the late stage of the aforementioned Sorath Harappan phase from about 1900 BC to 1600 BC (Possehl 1999: 18, 23) and, intriguingly, not the average value as far as port sites are concerned. Whether this is due to lack of sufficient, prospection or excavation is an open question. However, while not in the majority, this cultural phase is seen at Lothal (Possehl 1999: 790).

<u>"lustrous_red_ware = FALSE"</u>

A positive value for this attribute is not expected as lustrous red ware is more indicative of the Rajasthan region and elsewhere (Allchin and Allchin 1982: 262, 267, 277), although this distinctive pottery has been found at a few sites in the Gujarat, such as at Beyt Dwarka (Possehl 1999: 738) dated c.1600 BC to c.1300 BC (Possehl 1999: 18, 23, 64, Allchin and Allchin 1982: 242).

"late_harappan = TRUE"

A value of "False" for this attribute indicates that on average most port sites in the Gujarat span the late Harappan period from c.< 2000 BC to >1500 BC (Kenoyer 1997: Table 1, Kenoyer 2002: 2002: Table 1, Possehl 1999: 450, Possehl 2002: 66, Belcher 1997). Again, this provides dating criteria for radiocarbon analysis.

"red_polished_ware ="

This null value is certainly expected as red polished ware ceramics are dated from the non-Harappan Kushana nomadic culture of around 200 BC (Possehl 1999: 18, 23, Possehl 2002: 240, Chakrabarti 1999: 271).

7.3.3 Site Typlogy

"settlement = 1", "cemetery =" and "average_size_km_sq = 0.0335"

It is no real surprise that there are traces of settlement at most sites, otherwise, given the passage of time, it is difficult to envision as to how smaller, temporary camps may be detected other than by surface scatters. It also predicts that the average size of a Harappan port site in the Gujarat is quite small.

7.3.4 Field Work

"gps = FALSE", "excavated = 1" and "explored ="

It seems that in the Gujarat, on average at present, many of the sites found have also been excavated. Areas where some type of field work has taken place indicates that there is less likelihood of finding new sites in these areas simply because the area has been travelled to, and perused by, a person with, at least some semblance of archaeological experience or experience of the cultural landscape. This is because as archaeologists become more

accustomed to the landscape in which they work in, they are more likely to develop a more discriminating and experienced eye allowing them to perceive subtle differences in the landscape and, subsequently, the increasing the possibility of discovering well hidden neighbouring settlements. An example of this can be seen from the initial work of Rao with the Archaeological Survey of India.

With regard to the number of sites thus far identified in the landscape, through field work and excavations to date, Aston also draws attention to the continuing studies of village formation in England where the number of new sites has risen over the years. He states that the knowledge of the origin of villages, originates with a study of deserted villages in the 1940s, and by the 1970s, the work of a multi-disciplinary team of geographers, historians, archaeologists and natural scientists had revolutionised the concepts of rural settlement transformation over the last 2000 years particularly with the excavations at Wharram Percy in Yorkshire; in 1976 two thousand, eight hundred and thirteeen deserted villages have been identified (Aston 1985: 53). This number has risen over time because archaeological distribution maps only show the work of individual archaeologists or groups rather than a whole picture of deserted medieval villages (Aston 1985: 53).

7.3.5 Distribution Pairs, Percentage

<u>"north_dist = 54.76190" and "south_dist = 45.23810"</u>

Between the north and south half of the extent distribution only varies by approximately ten percent. This does not indicate a great deal as both areas have access to navigable water; the south by coast and the north by river.

<u>"east_dist = 71.42857" and "west_dist = 28.57143"</u>

There are far greater numbers of sites to the east indicating either the possibility of finding new sites in the east, or that there are many unexplored areas to the west.

"core_dist = 33.33333" and "periph_dist = 66.66667"

This indicates that there is no central hub at the centre of the extent at present. Other than the possibility of missing sites, another point to consider is that the extents of the settlement area may change over time as more sites are found outside this area, thus shifting the core and periphery zones in the direction of any of the cardinal points. It should be noted, however that Dholavira, by far the largest site thus discovered in the Gujarat is located twenty-three degrees, fifty three minutes and ten arc seconds north and seventy degrees, thirteen arc minutes east (Possehl 1999: 727-845). In terms of relative location to this core, it is located near the western edge of the northern border of the core zone at Khadir Island. Its central role (McIntosh and Weeks 2007: 208) is theorised by its size and complexity (Bisht et al 2000, Archaeological Survey of India 2009) and its location within the border defined by the model as a core zone, further adds validity to the predictions of the model.

7.3.6 Distribution Density

"most_sites = east" and "least_sites = west"

Most sites are located to the east of the extent which is interesting in that this is where the site of Lothal, a purported port by the minority of researchers, is located.

7.3.7 Geographical, Social and Political Models and Probability

"cpt_uniformity = Probability Low" and "nearest_neighbourliness = Probability Low"

Central Place Theory (CPT) assumes a uniform distribution of sites across a plane (Bradford and Kent 1986: 6-12); this result indicates that there is no real indication of such uniformity or that not enough sites have been found yet. Nearest neighbour (Barcelona Field Studies Centre 2008) type calculations attempt to quantify clustering, and again, no such patterns are to be found presently.

7.3.7 Unused

"lower_indus = FALSE"

This non-relevant result returns an obvious result, because the Indus River is located in Pakistan and not the Indian Gujarat, again only included as a fail safe measure.

7.4 Critique

7.4.1 Missing Critical Attributes

Possibly the most glaring criticisms of this model are the omission of clearly critical attributes found in other models. For example, one of the most useful measurements concerning water have been left out due to the focus on attempting to leverage and evaluate current data sources from other researchers. However, it would be a trivial matter to include these in future models. As it has been already mentioned, the salient factors concerning water are the distance to the nearest accessible drinking water and the distance to navigable water. A good topographic map and some investment, in future, should be all that is required to collect this data, though the process could be considerably more complex if a more in-depth analysis is to be performed. For example, the distinctions between "bay shoreline, river shoreline, brackish/salt creek shoreline, and fresh creek shoreline" (Kuiper and Wescott 1999).

7.4.2 Data Quantity

Many attributes have not been included due to limited research time. For instance, an elevation model is possible using the USGS contour maps and the methods described in the *Archaoprognose Brandenburg* mentioned in an earlier case study. Beach contour data

could also be obtained from marine navigation maps of the region. Other sources that could have been investigated, but were not, again due to time constraints, are possibly declassified Chinese, Soviet and American aerial photography and satellite remote sensing imagery from high altitude spy planes and spy satellites from the Cold War era that have no-doubt covered this area, particularly the more politically sensitive locations near the Pakistan and Indian border to the north. Obviously a lack of input data is detrimental to any model, no matter its sophistication. Jan van Dalen has researched the effectiveness of predictive modelling techniques by comparing a Bayesian model with a geometric model and has found that without sufficient data, in his case, the number of base maps, a model may not be particularly reliable (van Dalen 1999: 121).

7.4.3 Data Quality

The data sources used have been, to a large extent, unverifiable by, objective third party research. In most cases there is only one source of data which cannot be cross-checked, even if time permitted. Although it is not the purpose of this research to assign criticism to the quality other research used in the creation of the model, it is useful to point out some of the more notable problems with the data used. An example of this is the Gaur Coastline Reconstruction (Gaur and Vora 1999) where, after projecting the purported coastline onto a satellite map layer, some supposed port sites are found to have been wholly submerged during the Harappan era. In addition much of the Thakker findings are uncited and the Possehl data is rather brief. Also, various internet GIS forums indicate that the Falling Rain (Falling Rain 2009) altitude data is supposed to be derived from National Intelligence Mapping Agency (NIMA) (National Geospatial-Intelligence Agency 2009) data, however, how it is derived or what algorithm has been utilised to derive this data is unknown. In addition the NIMA data is also of unknown quality and derivation. This reliance of, essentially, data of unknown ultimate origin is uncomfortable from a scientific perspective. There are also many other examples of problems from almost all the data obtained for this research, however, not just the aforementioned. All these small errors have, as is common in any complex system, have a way of cascading or magnifying into larger errors and in this way it is not prudent to use the model designed in this research for anything other than identifying broad trends. In fact, no matter what type of modelling methodology is used to

build a model, it is obviously the quality of the data more than any other factor which will govern how effective any model can be. Again van Dalen critiques his own models and states that they suffer from a lack of sufficient interpretation of the source data and problems of accuracy stemming from the manual process for the digitisation and transcription of the maps used (van Dalen 1999: 121).

7.4.4 Data Type

Because many of the attributes from the Possehl data contain strings values, the SQL function of LIMIT has been used. As it has been stated before, there is a risk of this function not always returning the mode value. For this reason boolean data such as "TRUE" and "FALSE" should be converted to "0" or "1" in order that the simpler SQL numerical average function "AVG", may be used.

7.4.5 Testing Criteria

The quality of the data, although, from reputable sources, is not verifiable without additional fieldwork. Lab-testing has been possible by removing one site and comparing it with the average values obtained by combining all the other sites. However, with this test the assumption has to be made that the site the model has "found" is very similar or is a polar opposite of the removed site in order for some correlation to exist. For example, if the port site found by the model, in future proves to be is neither a port or an agricultural settlement, but a land-locked manufacturing centre, then the assumptions made as a basis for testing the model are incorrect.

7.4.6 Time Constraints

These lacks illustrate the most serious problems of predictive modelling and that is data quantity, quality and the sheer time consumed with creating these models. This time limitation is the factor that largely determines the problems with data quantity and quality

and is largely a fact of under-resourcing in archaeology in general and this research in particular.

7.4.7 Over Abstraction Versus Groundtruthing

As so much time has been spent with creating these models from what is essentially second hand, unverifiable data, it is possible the direct prospection or at least close, first hand inspection of the landscape may be preferable to relying on models for anything more than predicting general patterns. Although predictive modelling does constitute an, undoubtedly, valuable addition to the archaeological tool kit as long as it is used in addition to more traditional methods, to solely rely on a predictive model, no matter the probability of statistical accuracy is hazardous in terms of over-abstraction from the research matter. In this case the substitution of direct physical contact with the landscape for a virtual landscape made up of indirectly sourced data. Also there ultimately comes a point at which technology cannot offer additional resolution and more direct field studies are required (Cox 1992: 265).

7.4.8 Avoidance of Statistical Problems

A similar problem to over-abstraction concerns the common difficulty of the use of overly derived statistics has largely been avoided in this work. This problem has been avoided largely because of the knowledge that the data is limited in quantity and therefore there is a recognition of the temptation to pad the data quantity by deriving extra data from unjustified statistical techniques to identify relationships between entities that have a weak connection or even a non-existent correlation. For example, the relationship between the presence of anchor stones can, when one also takes into account a corresponding presence of shell remains or middens, give the false impression of a maritime, boat building culture. However, if upon further examination, the anchor stones are revealed to be millstones for the grinding of grain, the correlation between the shells and the stones collapses as does the previously certain assumption of maritime activities. Common pitfalls in the use of statistics (Caswell 1982:3) are a very prevalent trend in many disciplines and this condition has been studied in many other works .

7.4.9 Informational Scope

One valid problem with the model is that from an early point in the inception of the research the data sources identified and the information contained therein has been far too broad to tackle in this one research effort. As a result the data is shallow and somewhat diluted. In retrospect, a better strategy may have been to have selected far fewer attributes and study them in far greater detail, such as from the example of the Maryland Shipyards research mentioned earlier (see 1.5) which only uses six environmental factors- proximity to cities, shelter, slope and four soil related factors (Ford 2006: 125). This strategy of concentration on a small number of factors, but in high detail, can also be seen with data collection in the field, for example, at a detailed study of lithics at Wadi Araba in the south of Jordon (Henry et al 2001).

7.4.10 Geographic Scope

The initially thought rather small geographic area under examination, that is the Gujarat, is thought on reflection, to be too large and generic an area to produce site specificities. However, the cultural and archaeological differences have not been apparent until far too late in the development of the model. A better approach, though this can only be said in hindsight, may have been to limit the area to Saurashtra, the round, convex projection nestled between the Gulf of Cambay and the Gulf of Kutch (Possehl 1999: 157) as this area is distinct from the rest of the Gujarat.

7.4.11 Applicability of Central Place Theory to Archaeological Problems

As it has been mentioned earlier CPT is difficult to apply to archaeological problems with respect to site distribution (Johnson 1972: 181). Another criticism of CPT is its use in explaining state formation (Crumley 1976: 59). While perhaps problematic to use, it is at least of some utility in locational analysis (Crumley 1976: 69). It is the opinion formulated

during this research that it is impossible to fit any particular theory into a complex system, for example, one that involves a living system such as a human community. Any theory can only act as a guide. This need not necessarily be a disadvantage as it allows a flexible approach to real-world problems without the confines of rigid dogma. In any case most models in all fields of research, be they art or science, including CPT are, over time, subject to refinement (Ullman 1941: 853) and reinterpretation.

7.4.12 Dilution of Skill

It has become apparent that many different skills are needed to effectively model data based on wide range of disciplinary areas. A polymathematical approach is possible, but perhaps not always desirable for situations where a deeper understanding of the underlying implications of the results is required.

7.4.13 Z-Coordinates

As well as X and Y coordinates representing longitude and latitudes, Z values could also be assigned for height variances of each site. This could substantially change the dynamics of the results in other areas outside the Gujarat by underlining the differences between the lowland Harappan culture and its various highland extensions. However, in the Gujarat itself; the sites are fairly low-lying, thus negating any additional benefit of incorporating this proposed added functionality.

7.4.14 Software Distribution Difficulties

After the model building procedure has been completed, it has been found difficult to create a copy of the HPPPM that can be transferred to a CD-ROM because of Matlab which requires installation on a host computer before the model can be run. This, although, not a problem for the presentation of this research, it does pose a difficulty in future incarnations for a deployable field system, both in terms of cost for the proprietary

Matlab software and its deployment. Thus, it has been decided to experiment with alternative mathematical software. In order to minimise re-coding the software a near analogue to Matlab has been found in the shape of the FreeMat software application (Basu et al 2009). In fact, after a few slight alterations to the command line instruction for running the Matlab program in FreeMat, no additional changes were required to the Matlab code and the entire model is now portable requiring no installation. A further advantage is that the entire HPPPM is now only twenty-two megabytes in size compared to the previous three and a half gigabyte, that is , roughly fifteen times smaller, due to the removal of Matlab. FreeMat is also free and open source, thus, there are no financial costs to consider for licensing. The model also runs much faster as a result of using this lightweight product, timing tests show that it takes less than ten seconds to run in entirety, thus there is not further need to optimise any of the coding to enhance performance at present.

7.4.15 Shallow Understanding of State Polities

While research into site distribution patterns in the landscape is useful for the study of locational criteria, as is the case within this research, perhaps this leaves some deeper questions unanswered.

This is because of the difficulty in understanding complex state formation processes from only distribution patterns of sites. This type of understanding requires a geographical scope more wide-ranging than hinterlands and peer polities because one must also consider nomadic pastoralists and producers of raw materials, vital to a growing state who may be found far distances from urban concentrations; by this method it is possible to learn how diverse social and cultural groups have contributed to the evolution of social complexity and the state (Renfrew and Bahn 2005: 78).

7.5 Summary

Thus final HPPPM model has been run and results produced.

An analysis of the results suggest possibly erroneous aspects in the reconstruction of the Harappan age coastline of the Gujarat (Gaur and Vora 1999).

It also seems to demonstrate that the Harappan age in the Gujarat starts at a later date than elsewhere as, for example, the Indus Valley area.

The model further demonstrates, that most of the ports sites are located to the east and also that the central area intercepts the large and important Gujarat Harappan settlement of Dholavira.

Other than eastern the concentration, settlement patterns display a rather random distribution, in relation to each other and also show no particular clustering.

7.6 Conclusion

The model is useful because it uses very few over-derived statistical tests and the results are easy to understand.

The main disadvantage with this model does not concern the program design, but rather the data. This is because, although the data is as complete as possible given the limitations in terms of time and realistic expectations of what is achievable, it is still not satisfactory in either its quantity or quality and, in some cases, even its provenance.

One possible consideration, given the many possible variables identified for use, is to increase the number of attributes used. This method has been used in other archaeological modelling software such as FORDISC 3.0 (Ousley and Jantz 2005). However, whether this can work to the benefit or detriment of the final model is questionable, because of the dangers of statistical over-fitting; a problem that can occur where too many variables are used with too little data and, in fact, this is a criticism that has been made of the FORDISC software itself (Elliot 2008).

Another constraint has been the divided, and sometimes incompatible research objectives, which make it clear that this is both an exercise in testing the efficacy of predictive modelling as a technique, as well as, finding Harappan ports and from this point of view that is exactly what the research has attempted to do. The relative success or failure of this experiment in modelling will be analysed in the conclusion of this research.

8. Summary

The subject of this research has been to test the abilities of a multi-discipline site location predictive modelling software application, which can be useful where data is sparse, in order to understand the Harappan maritime trade network in the Gujarat, that is, the probability and placement of port sites and therefore, probable sea routes for trade and exchange activities.

The attributes selected for modelling include environmental features, cultural phases, site typology, previous field work and a set of calculations to determine pattern and density of the distribution of sites within the landscape.

The building of the model has entailed a background study of the Harappan Civilisation, which reveals it to appear short lived; from its gradual development from pastoral nomadism to farming villages in Baluchistan, spreading to the Indus plains and ending in

the refinement of planned Harappan cities.

Most relevant to this research, however, is the overwhelming evidence that long distance trade existed, as can be seen from presence of non-local material, artefacts and seals as well as the mechanisms such as large, well organised cities near navigable rivers, evidence of large scale manufacture as well as boats, a system of weight and measures, and an intergrated transport mechanism whereby goods were transported to and from port sites via a chain of water-borne vessels, pack animals and bullock carts. Vessels included short-range reed boats, small wooden boats and larger, shallow draft wooden sailing ships for seagoing voyages. Imports included gold from lower peninsula India, silver from Afghanistan and Iran, copper from Rajasthan, lapis lazuli from north-east Afghanistan and turquoise from central Asia or Iran. Exports probably included timber and manufactured luxury items. A ready market for goods in the west was the main driving force for developing these integrated transport networks, thus a study of traded items has also been conducted in this research.

The operation of the model has produced results suggesting a possibly erroneous reconstruction of the Harappan age coastline of the Gujarat (Gaur and Vora 1999). The results also indicate that Harappan age in the Gujarat started at a later date than elsewhere and that most of the ports sites were located to the east and that the central area intercepts the important settlement of Dholavira. Other than this eastern concentration, settlement patterns seem random. However, in final summation, it is fair to say that despite the lack of data, the model has proved useful because it uses very few overly derived statistical tests and the results are easy to understand while testing has also proven the outputs to be fairly accurate.

9. Conclusion

In conclusion of this research, a discussion is now offered regarding an interpretation of the HPPPM results, the extent to which the research has succeeded in fulfilling the aims set out in the abstract and how the HPPPM may be applied in other research.

9.1 HPPPM: Interpretation of Results

The research now attempts to extend the interpretation of the output of the HPPM in terms of distribution suggesting possible areas for new site discovery.

9.1.1 Distribution

As it has been mentioned earlier, the computation of distribution has been accomplished by superimposing a grid over the research area followed by a statistical evaluation by comparing the number of sites in each grid sector to total number of sites. This grid arrangement can be seen overleaf.

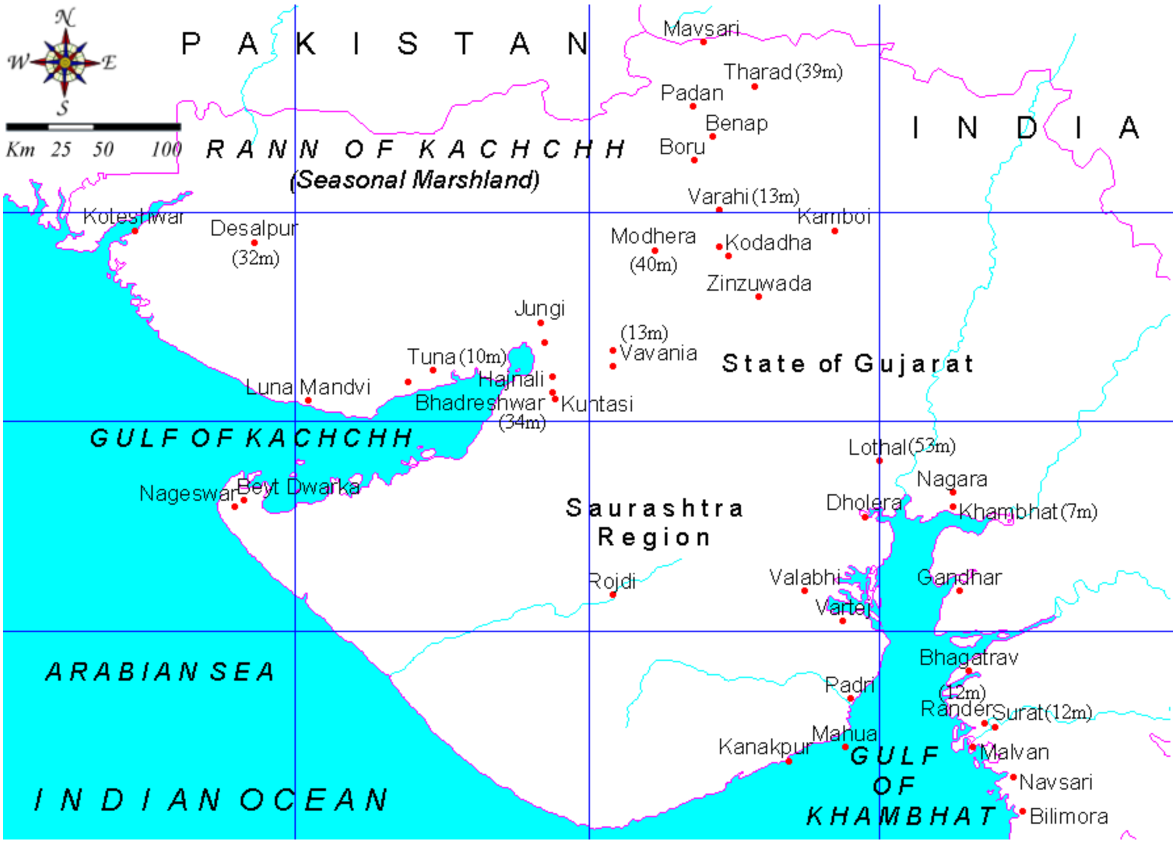


Figure 9.1 Grid Overlay

9.1.2 Possible Locations of New Sites

In terms of distribution, it has been found that most of the proposed ports sites are located to the east and other than this easterly concentration, settlement patterns display a rather random distribution in relation to each other and also show no specific cluster patterns. This easterly concentration can be seen in the highlighted area overleaf.

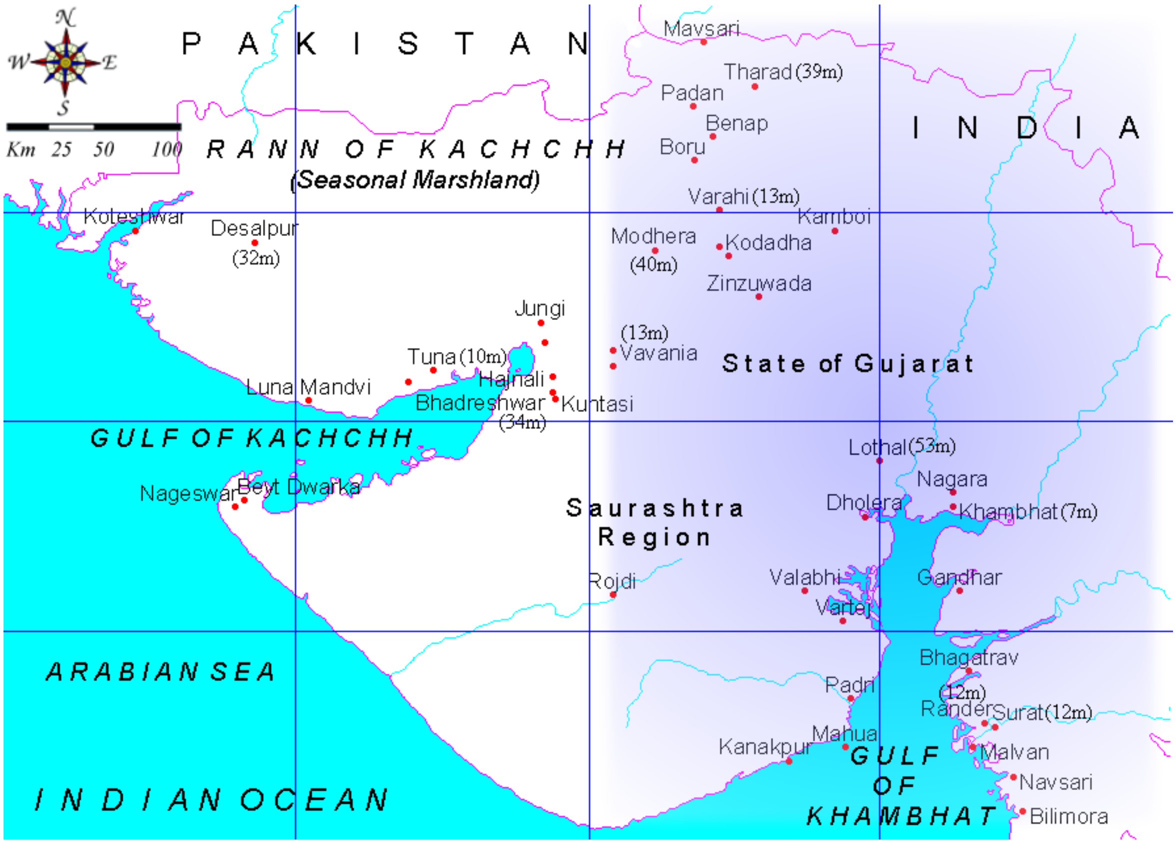


Figure 9.2 Results Easterly Concentration

However, the central area intercepts Dholavira, a the large and possibly an administrative centre of the region, this can be seen overleaf.

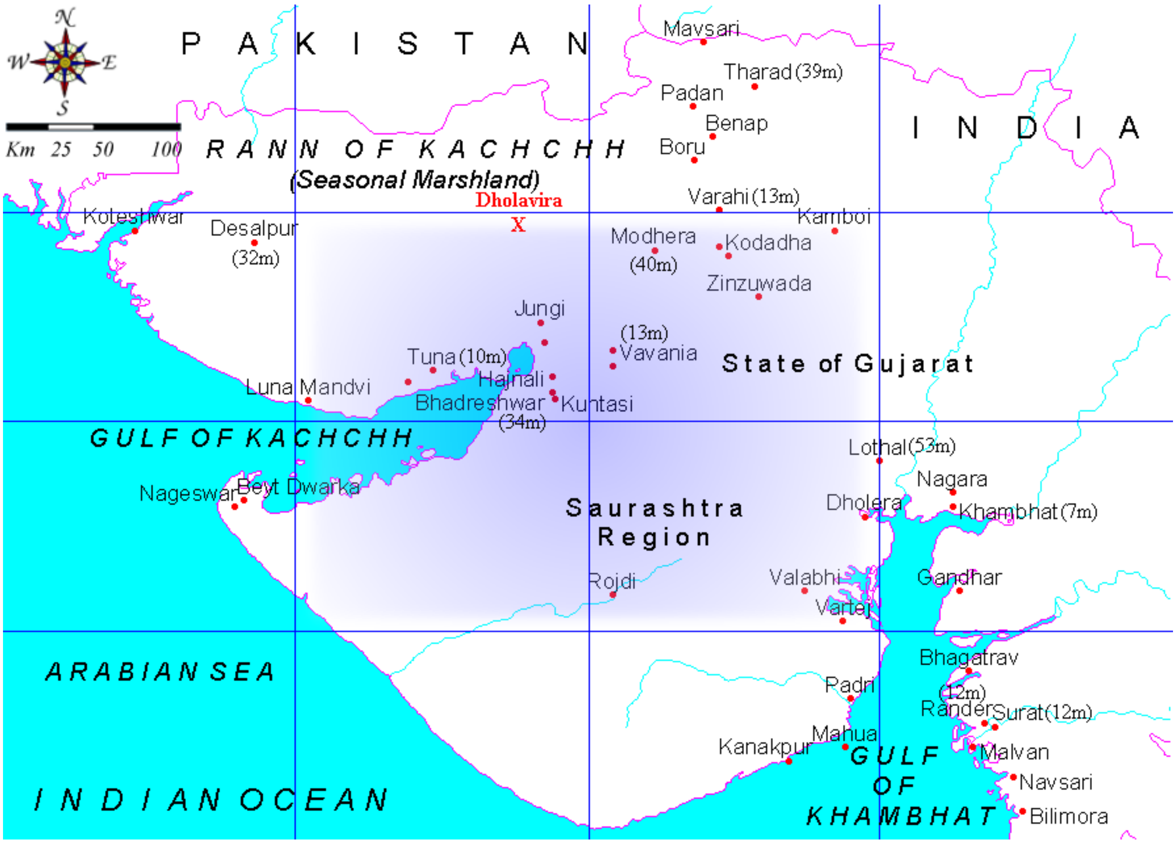


Figure 9.3 Results Core Area and Dholavira

Thus, bearing in mind the easterly concentration and also taking into account that ports, harbours and beaching sites are likely located near or on the coast and major rivers and if Dholavira is taken to be the dead centre of the Harappan Gujarat, by moving the grid to reflect the central location of Dholavira, site potentiality can be determined. The main areas, where it is proposed that new sites may be located, are shown on the following map.

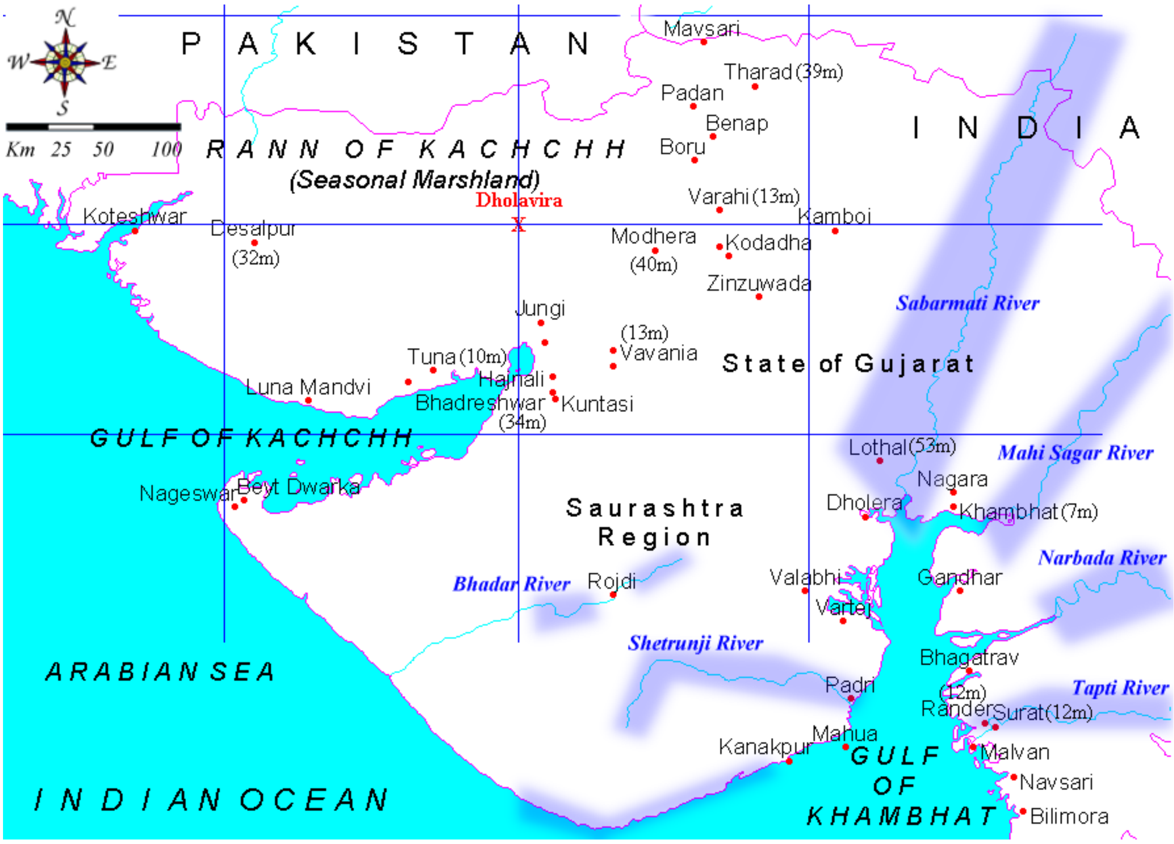


Figure 9.4 Dholavira Centred Grid

The new search areas that have been identified in this way are the Sabarmati river near Lothal, the Mahi Sagar river roughly north-east of Kambhat, the Narbada river east of Bhagatrav, the Tapti river east of Surat, the Bhadar river both east and west of Rojdi, the Shetrunji river west of Padri and the coast-line west of Kanakpur. It is interesting to note that Shetrunji has been explored before and twenty-two settlements have been discovered, though these have been dated to a later period of c.100 BC to c.100 AD (Himanshu 2003: 47). It is suggested that field based reconnaissance within these areas may produce hitherto undiscovered sites of the Harappan age forming part of a wider exchange network.

9.2 Questions from the Abstract Answered

A point-by-point analysis is now offered in order to determine to what extent the questions poised by the abstract have been answered.

9.2.1 The Effectiveness Computer-Based Predictive Modelling

"It is the aim of this research to test the hypothesis that computer-based predictive modelling can be effective as a site location tool and that these models can also be made more accurate by the inclusion of other factors such as geographical, social, economic and political theory, particularly where there are short-falls in the availability of environmental data traditionally used in such models. The effectiveness of this holistic, polymathematical approach drawing from many disciplines may be judged by its capacity to solve important archaeological questions. "

It is the opinion formulated from this research that predictive modelling for site location may be seen as a tool that is most useful at the feasibility stage or initial stage of a field reconnaissance. It is believed that the effect of sparse data has been somewhat ameliorated by the act of creating the model, however, the conclusions reached concerning uniformity and clustering have suffered from this same lack. Thus, while the development of a predictive model has enlightened knowledge concerningthe pattern of port distribution in the Gujarat, it is rather a preliminary step to a more detailed exploration by future

researchers. However, the model has been measurably successful in discovering new search areas (see 9.2.4 New Search Areas Identified by the HPPM).

9.2.2 Has the HPPPM Identified the Criteria for Identification of Harappan Port Cities?

"First, there is a need to properly identify Harappan port city criteria; a contentious issue as, thus far, there has been no consensus of what properly constitutes a Harappan port city, for example, the Lothal controversy. "

To a limited extent this has been answered, though more from a point of possible locations identified by the model, than by any structural criteria. The least that can be said of the areas identified is that, if in the future a major site is found next to one of the identified river banks or coastal areas it is probable that the settlement had at least some link with water borne trade, be it local or farther afield. To actually state that large-scale, international trade existed would require further excavation and an examination of the material remains to determine the probability, much in the same way as it has been attempted earlier (see 4.4. Trade Commodities). The various sides in the Lothal controversy have accomplished little other than casting doubt on whether the site was a port and this has rather side-stepped the more important issue of what a Harappan port is, in terms of buildings, layout and town-planning. Though whether this is an achievable and realistic goal is also debatable.

9.2.3 What Evidence has the HPPPM Revealed About Harappam Maritime Trade Networks?

"Secondly, by identifying these sites as well as their involvement in both intracultural and extracultural trade and exchange mechanisms and dynamics, the foundations of the Harappan maritime trade network may be further exposed and interpreted over time."

This question has been partially answered, both by the model and by other evidence. The model has shown urban concentration and densities of the cities proposed as ports by the Thakker research (Thakker et al 2000). Also an examination of the work of other researchers (see 4.8 Harappan Period Trading Networks) has shown both the larger sphere of the Middle Asian Interaction Sphere (Possehl 2002 : 216) and the more local integrated Harappan network has been proposed. In this local network goods arriving at port or market centres overland by cart, pack animal or small river-boat from the hinterlands. At the port the goods are are sorted, sealed and then sent out by cart to a beaching site where they are loaded onto larger sea vessels which navigate by dead-reckoning across the Arabian Sea and then on, perhaps, through the Gulf of Oman and up through the Persian Gulf until they reach Mesopotamia (see 4.8.2 Harappan Networks). The temporal aspect of these networks can be seen from the evidence of Pre-Harappan to at least Colonial period trade following roughly the same routes (see 4.3 Trade Partners).

9.2.4 New Search Areas Identified by the HPPM

"Thirdly, only a few of these sites have so far been discovered and, thus, there is a high probability that, given the geographical expanse, the area could have supported far more of these sites than have yet been found. Thus, new search areas need to be identified as a first step towards further exploratory archaeology. "

Even in a limited capacity the model has demonstrably assisted in providing new search areas. First, the reverse testing methodology has proved the model to be accurate (see 6.6 Software Test Documentation) and secondly and, perhaps more significantly, some of the areas identified have been found to be archaeologically rich through independent corroboration by other researchers, further validating the accuracy of this model (see 9.1.2 Possible Locations of New Sites).

9.2.5 The Application of Computer Technology During this Research

"Finally, as it has been stated that this is a multi-disciplinary approach drawing on various technological processes, it is necessary where appropriate, to use computer technology to aid in this research. "

It could be fairly stated that this entire research effort has been largely computer driven in almost every aspect. As well as the more obvious use of database technology in the predictive model (see 6.5.2 Development), agent based programming for the trade simulation (see 4.5 Trade Simulation) and the use of GIS systems such as ArcView (see 5.7 GIS Construction) there have also been the various scripts used in collecting, collating and managing data (see Appendix A). Also by referring back to the earlier software review (see 5.5. Software Review) it is possible to see how much reliance has been placed on modern computer hardware and software. Therefore, in retrospect, the question could be asked as to whether this research would have been possible before the advent of modern computer systems. Not only is the answer resoundingly negative, it is also possible that the research would have suffered severe difficulties without the creation of Google Earth in 2005.

9.3 The Application of HPPPM-like models for Site Potentiality

While examining archaeological predictive modelling in general it has becomes apparent that there are no "off-the-shelf" software available for general, multi-environment site location, because archaeological predictive modelling has, in the past, been more of a conceptual set of techniques applied to specific problems.

To a certain extent, this need not be the case. It has hopefully been shown during the course of this research that techniques such as simple database and statistical or mathematical tools commonly used in science are now of sufficient power to handle almost any type of predictive modelling task.

However it should also be stated that much of the proof of trade, ports and routes has come from sources other than those sourced directly from the predictive model. For example, it would have been impossible solely use the model to interpret trade and exchange relationships of the Harappans with other cultures without a further documentary examination of trade commodities as well as Pre-Harappan and Post-Harappan trade dynamics. This documentary evidence gathered from the work of other early scholars such as Wheeler, Rao and Fairservis and later scholars such as Ratnagar, Posseh1 and Kenoyer, mentioned throughout has revealed that during the Harappan Urban/Mature period, Mesopotamia was a vast consumer of trade commodities. Although limited in mineral wealth, it used its vast agricultural wealth to import goods from many places including the Harappan region. Many goods from the Harappans came by sea. Proof of this trade can be seen from many of the artefacts found in the archaeological record of both cultures, for example, Harappan seals and a Harappan weight found in Mesopotamia and also the Persian Gulf and the preponderance of Harappan artefacts in Mesopotamia. It should also be remembered that these same sea routes remain important to this day.

Also, it is strongly felt that the sole use of this type of model is not sufficient for accurate results, fieldwork is also recommended. In fact, this is where the model has its greatest strengths- in its ability to assist in predicting viable site potentiality prior to fieldwork. A good model can, therefore, also be considered both as a tool to aid field researchers and an aid to assist in initial feasibility studies as a justification for funding. It is also a useful tool in situations where local knowledge is sparse or the search areas are large.

9.4 Multi-Agent Modelling

Both to demonstrate evidence for maritime trade exchanges and to explore the use of decentralised systems modelling an experiment has been conducted using agent based programming to model trade between Mesopotamia and the Harappan Civilisation.

This model has been programming using the following rules- a large amount of goods can be transported fastest over water by ship, a medium amount of goods can be transported at

a slower pace over flat land using Harappan type bullock carts and a small amount of goods can be transported at an even slower pace over mountains by pack animals.

The model has assisted in confirming the validity of an integrated maritime network for bulk commodity transfer, which also, implies a large scale trade infrastructure, including financial machinery, organisation, a certain level of literacy and mathematics as well as connections between ports and their local hinterlands.

It also serves as an example of what is achievable using agent based programming tools, as well as suggesting future directions for research (see MIT Education 2005, Appendiz A: hartrade.slogo). Such future directions could include optical pattern matching to compare patterns in settlement shape in order to more clearly define the shape of settlements unique to a particular culture and purpose. Another way may be by modelling aspects such as trading behaviour or the evolution or demise of cities and societies.

10. Recommendations

10.1 The Future Possibility of an "off-the-shelf" Site Location Predictive Model

From what has been learned from the creation of the HPPM, it may be possible to create a simple model to aid general archaeological reconnaissance. In fact, this would be a much simpler operation, given that the model can be made to be strictly numeric and not have to contend with such anomalies as inaccurately formatted textual data and the almost certain requirement for far fewer fields in the database together with the use of the HPPPM as a design template.

10.2 Warnings Regarding Over-Abstraction

When building models, it is advisable to bear in mind the various dangers of over-abstraction and the differences between virtual and physical environments outside the computer, though this is a common problem for computer models and simulations in general.

10.3 Cost-Benefits of Modelling

Creating models can be cost effective in terms of research time consumption, however, it should be noted that the modelling stage of the research is not the most critical part of the research; ground-truthing is of far greater importance and if the model points the archaeologist in the right direction by way of most probable search areas then it can be deemed to be of great utility.

10.4 Using the Data in Future Research

The fields that define a Harappan port, based on the information available from the final complete data file produced have thus been identified, however, there is a great deal of data within this file concerning all Harappan sites, not merely those in the Gujarat. It seems, therefore, an opportunity to allow others to also attempt and identify the salient features of all Harappan sites and not just those of ports or, at the very least, have the opportunity to use the data in other research. For this reason the final data file with the combined data, from both Possehl, Thakker as well as that gathered during this research is supplied here as the file *harappan.csv* (Appendix A: harappan.csv).

10.5 Use of Artificial Intelligence in Archaeological Modelling

After investigations during the course of this research, it is thought that, in particular, these two disciplines can contribute to site location models.

With Artificial Intelligence (AI), expert systems techniques can be used to design rules-based predictive models by incorporating the criteria believed important for site location in this this research, for example, the distribution areas of possible new sites.

With Artificial Life (AL), it is also hoped that models may incorporate the capacity to analyse and compare graphical data as well as numerical data. This may be in the form of a pattern matching computer program using cellular automata or agent based software to compare patterns in settlement shape in order to more clearly define the shape of settlements unique to a particular culture and purpose, perhaps bearing in mind the lessons learned from the behaviour-based robotics paradigm of weak AI, where relatively simple modular algorithms are incorporated into a framework simulating intelligent behaviour. Another way to use agent based programming, may be by modelling aspects such as trading behaviour or the development and demise of cities and societies (see 9.4 Muli-Agent Modelling).

Afterword

This research has brought to light many practical problems involved in creating a coputer-based predictive model as well some of the flaws in taking a single environmental approach without considering theoretical approaches from other disciplines. However, the overriding opinion arrived at the end of this research is that no particular theoretical approach, whether it is environmental, social, economic or political fully provides a complete explanation of site distribution, cultural evolution, state formation or, in fact, the understanding of any complex system in science.

Butzer notes in the ongoing debate between the effectiveness of environmental attributes versus social theory attributes, that neither of these schools of thought fully explain human behaviour in terms of the capacity for people to adapt to ecological stress and in order to form a deeper, more personal, understanding of the people themselves an approach un-abstracted from theory is required (Butzer 2005: 1798).

Theory seems to offer a useful framework as a starting point on which to build from and, perhaps, should be viewed as an aid to intuition and experience, rather than a replacement.

Appendices

Appendix A: Contents of CD-ROM

Folder	Description
bath3d	Artistic 3D renderings of the Great Bath of Mohenjo daro (bath3d.bat)
conversi	Combined archaeological unit conversion calculator (conversi.bas)
fovcalc	Field of View Calculator (fovcalc.bas)
harappan	Complete data file for all Harappan sites (harappan.csv)
hartrade	Harappan Trade Simulation (hartrade.bat)
hpppm	Harappan Ports Project Predictive Model (\freemat\bin\harappan.bat)
nima	Automated NIMA GNS data extraction (nima.bas)
gis	Complete GIS project (gujarat.bat)
rps	Interactive Perl Shell (rps.pl)
rqs	Interactive BASIC Shell (rqs.bas)
rrs	Interactive Rexx Shell (rrs.rex)
superget	Automated google search (superget.bas)

Appendix B: Mesopotamian Place Names and Modern Names

Meluhha	(Harappan Civilisation)
Dilmun	(Bahrain)
Magan	(Oman)
*Ur	(near An Nasiriya in S Iraq, several km W of the Euphrates)
*Uruk	(c.15 km E of the Euphrates, 250 km S of Baghdad)

*(Fagan 1996)

Appendix C: Early Mesopotamia

First Dynasty of Kish	c. 2592 BC to 2568 BC
First Dynasty of Ur	c.2563 BC to 2387 BC
Dynasty of Lagash	c.2494 BC to 2342 BC
Third Dynasty of Uruk	c.2340 BC to 2316 BC
Dynasty of Akkad:	c.2334 BC to 2154 BC
Fifth Dynasty of Uruk	c. 2122 BC to 2113 BC
Third Dynasty of Ur	c.2111 BC to 2004 BC
Dynasty of Isin	c.2019 BC to 1794 BC
Dynasty of Larsa	c.2026 BC to 1763 BC
Babylonian conquest	c. 1763 BC

(Morby 2002)

Glossary

1st Generation Languge, (1GL)
2nd Generation Languge, (2GL)
3rd Generation Languge, (3GL)
4th Generation Languge, (4GL)
Artificial Intelligence, (AI)
Artificifial Life, (AL)
Beginners All Purpose Symbolic Instruction Code, (BASIC)
British Broadcasting Company, (BBC)
Computed Tomography, (CT)
Computer Aided Design, (CAD)
Computer Aided Tomography, (CAT)
Cultural Resource Management, (CRM)
FORmula TRANslator, (Fortran)
Graphical User Interface, (GUI)
Graphical VIMproved, (GVIM)
Ground-penetrating radar, (GPR)
Harappan Ports Project Predictive Model, (HPPPM)
Information Technology, (IT)
Instrument to measure magnetic susceptibility and conductivity, (Slingram)
Integrate Development Environment, (IDE)
Kite Aerial Photography, (KAP)
LISProcessor a programming language, (LISP)
Large Japanese TV compnay , (NHK)
National Aeronautics and Space Administration, (NASA)
Practical Extraction and Reporting Language, (Perl)
Programming in Logic, (Prolog)
REstructured EXecutor, (Rexx)
Rapid Application Design, (RAD)
Relational Database Management System, (RDBMS)
Simple graphics and list based programming languge, (Logo)
StarLogo, A massively parallel programming lanagauge

Structure Query Language for programming RDBMS, (SQL)

UNIX, An operating system, e.g. BSD/SunOS/Linux

Vi Improved (VIM)

Vi, A visual editor for UNIX

Win32, An MS Windows 32 bit operating system e.g. NT/2000/XP/Vista/7

Bibliography

ABATE, TOM (1994) Climate and the Collapse of Civilization, in *BioScience*, Vol. 44, No. 8 (Sep., 1994), pp. 516-519, United States of America: American Institute of Biological Sciences
[Accessed 15/06/2009]
http://www.jstor.org/stable/1312276

ABER, JAMES S. and ABER, SUSAN W. (2002) Unmanned Small-Format Aerial Photography from Kites for Acquiring Large-Scale, High-Resolution, Multiview-Angle Imagery, in *Image Data Acquisition - Sensors and Platforms, Pecora 15/Land Satellite Information IV/International Society for Photogrammetry and Remote Sensing(ISPRS) Commission I/FIEOS 2002 Conference Procedings*
[Accessed 05/05/2005]
http://www.isprs.org/commission1/proceedings/paper/00098.pdf

ABRAMS, PHILIP II and WRIGLEY, EDWARD ANTHONY (1978) *Towns in Societies*, United Kingdom, Bristol: Western Printing Services Ltd, ISBN 0 521 21826 8

AGRAWAL, D.P. and TIWARI, LALIT (2004) *Ancient Ship-Building & Maritime Trade*
[Accessed 28/09/2004]
http://www.infinityfoundation.com/mandala/t_es/t_es_agraw_ships.htm

ALLCHIN, B. and ALLCHIN, R. (1982) *The Rise of Civilisation in India and Pakistan*, Cambridge, United Kingdom: CUP, ISBN 052128550X

ALLCHIN, B., and ALLCHIN, R. (1997) *Origins of a Civilization: The pre-history and early archaeology of South Asia*, India, New Delhi, Viking Books

ALLCHIN, BRIDGET AND GOUDIE, ANDREW (1971) Dunes, Aridity and Early Man in Gujarat, Western India, in *Man*, New Series, Vol. 6, No. 2 (Jun., 1971), pp. 248-265
[Accessed 29/12/2007]
http://www.jstor.org/stable/2798265

ALLEN Jr., CALVIN H. (1981) *The Indian Merchant Community of Masqa*, in Bulletin of the School of Oriental and African Studies, Vol. 44, No. 1. (1981), pp. 39-53, United Kingdom, London: University of London

ALLEN, KATHLEEN M. SYDORIAK (2000) Considerations of Scale, in *Practical Applications of GIS for Archaeologists*, edited by Westcott, Konnie L. and Brandon, R. Joe, Chapter Six, p.107, 2000, United Kingdom, London: Taylor and Francis Ltd., ISBN 0-7484-0830-4

ALTSCHUL, JEFFREY (1988) Models and the Modeling Process, in *Quantifying the present and predicting the past: theory, method, and application of archeological predictive modeling*, edited by W. Judge and L. Sebastian, pp. 61-96, United States of America, Washington: U.S. Dept. of the Interior, Bureau of Land Management, U.S. Government Printing Office

ANTHONY, DAVID W. (1990) Migration in Archeology: The Baby and the Bathwater, in *American Anthropologist*, New Series, Vol. 92, No. 4. (Dec., 1990), pp. 895-914.
[Accessed 24/08/2007]
http://www.jstor.org/stable/680046

ARAMBURU-CABO, MARIA JOSE and LLAVORI, RAFAEL-BERLANGA (1998) A Retreival Language of Historical Documents, in *Proceedings of the 9th International Conference of Database and Expert Systems Applications (DEXA'98),* in Vienna, Austria, August 1998, part of the Lecture Notes in Science Series, edited by Goos, G., Hartmanis, J. and van Leeuwen, J., Germany: Springer-Verlag, ISBN 3-54064950-6

ARCHAEOLOGICAL SURVEY OF INDIA (2009) *Excavations - Dholavira*, India, Delhi: Archaeological Survey of India
[Accessed 01/07/2009]
http://asi.nic.in/asi_exca_2007_dholavira.asp

ARCHAEOLOGY (2009) Under Threat, in *Archaeology*, Features, Volume 62 Number 1, January/February 2009, United States of America, New York: Archaeological Institute of America, ISSN 0003-8113
http://www.archaeology.org/0901/topten/threatenedsites.html

ARNOLD, JEANNE E. (2000) Revisiting Power, Labour Rights and Kinship: Archaeology and Social Theory in *Social Theory in Archaeology*, edited by Schiffer, Michael Brian, Chapter I, United States of America, Utah: University of Utah Press ISBN 0-87480-642-9

ASTON, MICHAEL (1985) *Interpreting the Landscape*, United Kingdom, London: Taylor and Francis Group, Routledge ISBN 0-203-75036-5

ASTON, M. (2000) *Mick's Archaeology*, United Kingdom, Gloucestershire: Tempus Publishing Ltd. ISBN 0752414801

AUGUSTIN, NICOLE H., CUMMINS, ROGER P. and FRENCH, DONALD D. (2001) Exploring Spatial Vegetation Dynamics Using Logistic Regression and a Multinomial Logit Model, in the *Journal of Applied Ecology*, Vol. 38, No. 5 (Oct., 2001), pp. 991-1006, United Kingdom: British Ecological Society
[Accessed 15/06/2009]
http://www.jstor.org/stable/827238

AUTODESK (2000) *AutoCAD 2000*, United States of America: Autodesk Inc.

AVENI, ATHONY F. (1980) *Skywatchers of Ancient Mexico*, United States of America, Texas, Austin: University of Texas Press, ISBN 0-292-77557-I

AXTELL, ROBERT L., EPSTEIN, JOSHUA M., DEAN, JEFFREY S., GUMERMAN, GEORGE J., SWEDLUND, ALAN C., HARBURGER, JASON, CHAKRAVARTY, SHUBHA, HAMMOND, ROSS, PARKER, JON, and PARKER, MILES (2002) Population growth and collapse in a multiagent model of the Kayenta Anasazi in Long House Valley, in the *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 99, No. 10, Supplement 3: Arthur M. Sackler Colloquium of the National Academy of Sciences. Sackler Colloquium on Adaptive Agents, Intelligence, and Emergent Human Organization: Capturing Complexity though Agent-Based Modeling (May 14, 2002), pp. 7275-7279, United States of America: National Academy of Sciences
[Accessed 28/11/2005]
http://www.jstor.org/stable/3057853

BADENHORST, SHAW (2007) *Conversation between Mathur, R. and Badenhorst*, S. (an archaeological researcher) regarding settlements with partial views of the sky, Friday 07/07/2007 c.14.00, Canada, British Columbia, Burnaby, Simon Fraser University

BAITY, ELIZABETH CHESLEY (1973) Archaeoastronomy and Ethnoastronomy So Far, in *Current Anthropology*, Vol. 14, No. 4 (Oct., 1973), pp. 389-449, United States of America, Chicago: The University of Chicago Press on behalf of Wenner-Gren Foundation for Anthropological Research
[Accessed 09/07/2009]
http://www.jstor.org/stable/2740842

BARCELONA FIELD STUDIES CENTRE (2008) *Nearest Neighbour Analysis*
[Accessed 28/11/2008]
http://geographyfieldwork.com

BARRETT, GILLIAN (2002) Flights of Discovery: Archaeological Air Survey in Ireland, 1989-2000, *The Journal of Irish Archaeology*, Vol. 11, (2002), pp. 1-29, Wordwell Ltd.
[Accesedd 15/06/2009]
http://www.jstor.org/stable/30001657

BARSH, RUSSEL LAWRENCE and MARLOR, CHANTELLE (2003) Driving Bison and Blackfoot Science, in *Human Ecology*, Vol. 31, No. 4 (Dec., 2003), pp. 571-593, Springer
http://www.jstor.org/stable/4603493

BASU, SAMIT et al (2009) *FreeMat FAQ*, Source Forge
[Accessed 27/06/2009]
http://freemat.sourceforge.net/faq.html

BBC (2002) India's 'miracle river', excerpt from news programme broadcast on *BBC News*, Saturday, 29 June, 2002
[Accessed 22/09/2005]
http://news.bbc.co.United Kingdom/1/hi/world/south_asia/2073159.stm

BBC (2007) Timeline: The history of the internet, in *BBC News*, 23 August 2007
[Accessed 20/09/2009]
http://news.bbc.co.uk/2/hi/technology/6959933.stm

BECKER, CORNELIA and HÜNEMÖRDER, CHRISTIAN (2009) Elephant, in *Antiquity* volumes, Brill's New Pauly, edited by Hubert Cancik and Helmuth Schneider, Brill
[Accesed 15/062009]
http://www.brillonline.nl.libproxy.york.ac.uk/subscriber/entry?entry=bnp_e328780

BEDIGIAN, DOROTHEA and HARLAN, JACK R. (1986) Evidence for Cultivation of Sesame in the Ancient World, in *Economic Botany*, Vol. 40, No. 2 (Apr. - Jun., 1986), pp. 137-154, Springer on behalf of New York Botanical Garden Press
[15/06/2009]
http://www.jstor.org/stable/4254846

BEEKMAN, CHRISTOPHER S. (2005) Agency, Collectivities, and Emergence: Social Theory and Agent Based Simulations, in *Non Linear Models for Archaeology and Anthropology*, (Editor) Beekman, Chrstopher, S. and Baden, William W., United Kingdom, Hampshire, Aldershot: Ashgate Publishing Limited, ISBN 0-7546-4319-0

BELCHER, WAYNE (1997) *Harappa in 3-D*, Harappa.com
[Accessed 09/06/2009]
http://www.harappa.com/3D/captions.html

BENTLEY, JERRY H. (1996) Cross-Cultural Interaction and Periodization in World History, in *The American Historical Review*, Vol. 101, No. 3 (Jun., 1996), pp. 749-770, United States of America: American Historical Association
[Accessed 12/12/20002]
http://www.jstor.org/stable/2169422

BEVAN, ANDREW and CONOLLY, JAMES (2004) GIS, Archaeological Survey, and Landscape Archaeology on the Island of Kythera, Greece, in the *Journal of Field Archaeology*, Vol. 29, No. 1/2 (Spring, 2002 - Summer, 2004), pp. 123-138, United States of America, Boston: Boston University
[Accessed 15/06/2009]
http://www.jstor.org/stable/3181488

BHAN, KULDEEP K. and AJITHPRASAD P. (2008) *Excavations at Shikarpur 2007-2008: A Coastal Port and Craft Production Center of the Indus Civilisation in Kutch, India, an essay*, harappan.com
[Accessed 29/01/2009]
http://www.harappa.com/goladhoro/Excavations-at-Shikarpur-2007.pdf

BHARWADA, CHARUL and MAHAJAN, VINAY (2002) Drinking Water Crisis in Kutch: A Natural Phenomenon? In *Economic and Political Weekly*, Vol. 37, No. 48 (Nov. 30 - Dec. 6, 2002), pp. 4859-4866, India, Mumbai: Economic and Political Weekly
[Accessed 09/07/2009]
http://www.jstor.org/stable/4412909

BIAGI, PAOLO and CREMASCHI, MAURO (1988) The Early Palaeolithic Sites of the Rohri Hills (Sind, Pakistan) and Their Environmental Significance, in *World Archaeology*, Vol. 19, No. 3, New Directions in Palaeolithic Archaeology (Feb., 1988), pp. 421-433, United Kindom, London: Taylor & Francis, Ltd
[15/06/2009]
http://www.jstor.org/stable/124609

BIDGER, MARK (2007) Logistic regression, on *Numb3rs Blog* webpage April 4, 2006, United States of America: North Eastern University
[Accessed 03/09/2007]
http://www.atsweb.neu.edu/math/cp/blog/regression/regression.htm

BISHT, R. S., ISHIZAWA, OSAMU, IWATA, YASUYO and MATSUDA, NOBUYUKI (2000) *Indus Civilization: Computer Graphics Reconstruction of Dholavira*, India, Delhi: Archaeological Survey of India and Japan, Tokyo: Taisei Corporation in collaboration with NHK
[Accessed 01/07/2009]
http://pubweb.cc.u-tokai.ac.jp/indus/english/2_4_03.html

BLEED, PETER (1991) Operations Research and Archaeology, in *American Antiquity*, Vol. 56, No. 1. (Jan., 1991), pp. 19-35
[Accessed 24/08/2007]
http://www.jstor.org/stable/280969

BORLAND (1988) GEOBASE: The Geography database with a natural language interface, Packaged with *Borland Turbo Prolog 2.0*, Borland International, Inc

BRADFORD, M.G. and KENT, W.A. (1977) Human Geography: Theories and Their Applications, United Kingdom, Oxford: Oxford University Press. ISBN 0 19 913227 5

BRADLEY, RICHARD (1993) An Interview With Colin Renfrew, in *Current Anthropology*, Vol. 34, No. 1 (Feb., 1993), pp. 71-82, United States of America, Chicago: The University of Chicago Press on behalf of Wenner-Gren Foundation for Anthropological Research
[Accessed 15/06/2009]
http://www.jstor.org/stable/2743737

BRANDT, ROEL; GROENEWOUDT, BERT J.; KVAMME, KENNETH L. (1992)
An Experiment in Archaeological Site Location: Modeling in the Netherlands using GIS Techniques, in *World Archaeology*, Vol. 24, No. 2, Analytical Field Survey. (Oct., 1992), pp. 268-282
[Accessed 03/09/2007]
http://www.jstor.org/stable/124828

BREEN, COLIN and LANE, PAUL J. (2003) Archaeological Approaches to East Africa's Changing Seascapes, in *World Archaeology*, Vol. 35, No. 3, Seascapes (Dec., 2003), pp. 469-489, United Kingdom, London: Taylor & Francis Ltd
[Accessed 15/06/2009]
http://www.jstor.org/stable/4128321

BRENNAN, MARTIN (1983) *The Stars and the Stones*, United Kingdom, London: Thames and Hudson Ltd.

BRITISH MUSEUM (2003) *Small inscribed clay balls*, Asian Collection at the British Museum, Accession Number Unknown, United Kingdom, London: the British Museum

BRITISH MUSEUM (2004) *British Museum Teaching Resource*, at the British Museum, United Kingdom, London: the British Museum
[Accessed 22/05/2005]
http://www.ancientindia.co.uk/staff/resources/background/bg23/home.html

BRITISH MUSEUM (2009) *The Rassam Obelisk*, at the British Museum, ME 118800;ME 136897;ME 136898, Room 89: Assyrian Life, excavated by Hormuzd Rassam, United Kingdom, London: the British Museum
[Accessed 15/06/2009]
http://www.britishmuseum.org/explore/highlights/highlight_objects/me/t/the_rassam_obelisk.aspx

BROGGER, A.W (1951) *The Viking Ships*, first published in United States of America, New York: Twayne Publishers Inc, Reprinted in Norway, Oslo: Centraltrykkeriet, ISBN 82 09 00030 6 and 4

BROOKS, STEPHEN P. (2009) Bayesian Computation: A Statistical Revolution, in *Philosophical Transactions: Mathematical, Physical and Engineering Sciences*, Vol. 361, No. 1813, Mathematics, Physics and Engineering (Dec. 15, 2003), pp. 2681-2697, United Kingdom, London: The Royal Society
[Accessed 15/06/2009]
http://www.jstor.org/stable/3559268

BRUNSWIG Jr, ROBERT H. (1973) Prospective Tree-Ring Calibration of the Indus Civilisation Radiocarbon Chronology, *Man*, New Series, Vol. 8, No. 4 (Dec., 1973), pp. 543-554, Royal Anthropological Institute of Great Britain and Ireland
[Accessed 06/06/2009]
http://www.jstor.org/stable/2800739

BUCK, CAITLIN E. and SAHU, SUJIT K. (2000) Bayesian Models for Relative Archaeological Chronology Building, in *Applied Statistics*, Vol. 49, No. 4 (2000), pp. 423-440, United Kingdom, London: Blackwell Publishing for the Royal Statistical Society
[Accessed 01/01/2008]
http://www.jstor.org/stable/2680779

BURKE, GARANCE (2005) Virtual Journey Inside A Mummy, article in The Vancouver Sun, Friday August 5th 2005, Associated Press/Courtesy Silicon Graphics Inc., Stanford University and Volume Graphics GMBH

BUTLER, DECLAN (2005) Enthusiast uses Google to reveal Roman ruins, *Nature.com* [Accessed 21/10/2005].
http://www.bioedonline.org/news/news.cfm?art=2029

BUTLER, WILLIAM B. (1987) Significance and Other Frustrations in the CRM Process (in Forum), in *American Antiquity*, Vol. 52, No. 4. (Oct., 1987), pp. 820-829.
[Accessed 24/08/2007]
http://www.jstor.org/stable/281390

BUTZER, KARL W. (2005) Environmental history in the Mediterranean world: cross-disciplinary investigation of cause-and-effect for degradation and soil erosion, in *Journal of Archaeological Science*, Volume 32, Issue 12, December 2005, Pages 1773-1800
Downloaded from ScienceDirect.com 19/06/2007

CALLAWAY, EWEN (2009) Scholars at odds over mysterious Indus script, in *New Scientist*, Life, 23 April at 19:00, Issue 2706
[Accessed 07/06/2009]
http://www.newscientist.com/article/dn17012-scholars-at-odds-over-mysterious-indus-script.html

CARTER, ROBERT (2005) Boat remains and maritime trade in the
Persian Gulf during the sixth and fifth millennia BC, in *Antiquity*, 80 (2006): 52–63
Received: 6 September 2004; Revised: 21 March 2005; Accepted: 3 May 2005

CASSON, LIONEL (1984) *Ancient Trade and Society*, in Chapter 8, Rome's Trade with the East: The Sea Voyage to Africa and India, page 190, United States of America, Detroit: Wayne State University Press, ISBN 0-8143-1740-5

CASSON, LIONEL (1989) *The Periplus Maris Erythraei: Text With Introduction, Translation, and Commentary*, translation of text written by anonymous author in c.100-300BC, United States of America: Princeton University Press, ISBN 0-691-04060-5

CASWELL, FRED (1982) *Success in Statistics*, United Kingdom, London: John Murray (Publishers) Ltd., ISBN 0-7195-3902-1

CHAKRABARTI, DILIP K. (1975) Gujarat Harappan Connection with West Asia: A Reconsideration of the Evidence, in *Journal of the Economic and Social History of the Orient*, Vol. 18, No. 3 (Oct., 1975), pp. 337-34, BRILL
[Accessed 06/06/2009]
http://www.jstor.org/stable/3632141

CHAKRABARTI, D.K. (1999) *India: An Archaeological History*, India, New Delhi: OUP, ISBN 0195658809

CHAKRABARTI, D.K. (Editor) (2004) *Indus Civilization Sites In India: New Discoveries*, Vol. 55, No.3, India, Mumbai: Marg Publication, ISBN 81-85026-63-7

CHAKRABORTY, APARAJITA (1983) The Social Formation of the Indus Society, in the *Economic and Political Weekly*, Vol. 18, No. 50 (Dec. 10, 1983), pp. 2132-2138, India, Mumbai: Economic and Political Weekly
[Accessed 15/06/2009]
http://www.jstor.org/stable/4372775

CHANG, K.C. (1975) Ancient Trade as Economics or as Ecology, in *Ancient Civilisations and Trade*, Chapter 5, p.211, School of American Research Advanced Seminar Series, United States of America, Albuquerque, University of New Mexico Press, ISBN 0-8263-0345-5

CHEW, SING C. (2001) *World Ecological Degradation: Accumulation, Urbanization, and Deforestation, 3000 BC-2000 AD*, United States of America, California: Altimira Press, ISBN 0-7591-0030-6

CHITALWALA, Y.M. (2004) The Spread of the Harappan Civilisation in Kutch and Saurashtra, in *Indus Civilization Sites In India: New Discoveries*, Vol. 55, No.3, 2004, By Chakrabarti, D.K. (Editor), India, Mumbai: Marg Publication, ISBN 81-85026-63-7

CHURCH, TIM, BRANDON, R. JOE, and R. BURGETT, GALEN (2000) GIS Applications in Archaeology: Method in Search of Theory, in *Practical Applications of GIS for Archaeologists: A Predictive Modeling Toolkit*, edited by Wescott, Konnie L and Brandon, Joe R., United Kingdom, London: Taylor and Francis, ISBN 0-203-21213-4

CICERO, MARCUS TULLIUS (44 BC) *De Officiis*, this version translated in 1902, relevant section from Book III, section XII appears in this copy on page 223, United Kingdom, London: A. L. Humphreys
[Accessed 09/07/2009]
http://www.archive.org/stream/deofficiis00cicerich

CLARK, JEFFREY, T. and HAGEMEISTER, EMILY M. (Editors) (2006) Digital Discovery: Exploring New Frontiers in Human Heritage CAA2006 Computer Applications and Quantitative Methods in Archaeology, in the *Proccedings of Computer Applications in Archaeology Conference 2006*, Fargo, North Dakota, United States of America, Hungary, Budapest: Archaeolingua
[Accessed 20/06/2009]
http://www.leidenuniv.nl/caa/proceedings/caa_2006_proceedings.htm

CLOCKSIN, W.F. and MELLISH, C.S. (1987) *Programming in Prolog*, Germany, Berlin: Springer-Verlag, ISBN 0 387 17539 3

CODD, EDGAR F. (1969) *Derivability, Rendundancy and Consistency of Relations Stored in Large Data Banks*, in IBM Research Report RJ599, August 19th

COLELLA, V., KLOPFER, E., AND RESNICK, M. (2001) Adventures in Modeling: Exploring Complex, Dynamic Systems with StarLogo, United States of America, New York: Teachers College Press

CONWAY, MARTIN (1911) Some Approximations, in *The Burlington Magazine for Connoisseurs*, Vol. 19, No. 102 (Sep., 1911), pp. 338-344, United Kingdom: The Burlington Magazine Publications, Ltd
[Accessed 12/06/2009]
http://www.jstor.org/stable/858708

CONOLLY, JAMES and LAKE, MARK (2006) *Geographical Information Systems in Archaeology*, Cambridge Manuals in Archaeology, United Kingdom, Cambridge:Cambridge University Press, ISBN-13: 9780521793308

COPELAND, JACK (2000) What is Artificial Intelligence? At *AlanTuring.net*, Reference Articles,
May 2000
[Accessed 07/02/2006]
http://www.alanturing.net/turing_archive/pages/Reference%20Articles/what_is_AI/What%20is%20AI07.html

CORK, EDWARD (2005) Peaceful Harappans? Reviewing the evidence for the absence of warfare in the Indus Civilisation of north-west India and Pakistan (c. 2500-1900 BC), in *Antiquity*, Volume: 79 Number: 304 Page: 411–423, United Kingdom, Durham: University of Durham, Department of Archaeology
[Accessed 07/05/2008]
http://www.antiquity.ac.uk/Ant/079/0411/ant0790411.pdf

COVINGTON MICHAEL (1992) Demonstration expert system, in the *Dictionary of Computer Terms*, Downing, Douglas and Covington, Michael, United States of America, New York: Barron's Educational S eries, Inc., ISBN 0-8120-4824-5

COVINGTON MICHAEL (1994) *Natural Language Processing for Prolog Programmers*, United States of America, New Jersey: Prentice-Hall, Inc., ISBN 0-13-629213-5

COWGILL, GEORGE L. (1967) Computer applications in archaeology, in the *Proceedings of the November 14-16, 1967, Fall Joint Computer Conference*, Anaheim, California, Computing in the humanities and social sciences - a status report table of contents, Pages 331-337, United States of America, New York: ACM
[Accessed 07/06/2009]
http://doi.acm.org/10.1145/1465611.1465654

COX, CHRIS (1992) Satellite Imagery, Aerial Photography and Wetland Archaeology: An Interim Report on an Application of Remote Sensing to Wetland Archaeology: The Pilot Study in Cumbria, England, in *World Archaeology*, Vol. 24, No. 2, Analytical Field Survey (Oct., 1992), pp. 249-267, United Kingdom, London: Taylor and Francis Ltd.
[Accessed 09/07/2009]
http://www.jstor.org/stable/124827

CREVIER, DANIEL (1993) *AI: The Tumultuous History of the search for Artificial Intelligence*, United States of America, New York: BasicBooks, ISBN 0-465-02997-3

CRUMLEY, CAROLE L. (1976) Toward a Locational Definition of State Systems of Settlement, in *American Anthropologist*, New Series, Vol. 78, No. 1. (Mar., 1976), pp. 59-73, United States of America: American Anthropological Association
[Accessed 24/08/2007]
http://www.jstor.org/stable/675030

CUSTER, JAY F.; EVELEIGH, TIMOTHY; KLEMAS, VYTAUTAS; WELLS, IAN (1986) Application of LANDSAT Data and Synoptic Remote Sensing to Predictive Models for Prehistoric Archaeological Sites: An Example from the Delaware Coastal Plain, in *American Antiquity*, Vol. 51, No. 3. (Jul., 1986), pp. 572-588
[Accessed 03/09/2007]
http://www.jstor.org/stable/281753

D'ANDREA, C. (2003) *Arch 272 Week 12 Lecture 10: Harappan Civilisation*, Lecture notes and Microsoft Powerpoint slide-show for lecture, Canada, Burnaby, BC: Simon Fraser University

DAINTITH, JOHN and WRIGHT, EDMUND (Editors) (2008) "pattern recognition", in *A Dictionary of Computing*, Oxford Reference Online, United Kingdom, Oxford: Oxford University Press
[Accessed 21/06/2009]
http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t11.e3823

DALEN, JAN VAN (1999) Probability Modelling: A Bayesian and Geometric Example, in *Geographical Information Systems and Landscape Archaeology*, Gillings, Mark (Editor) et al, Chapter 11, p.117-124, United Kingdom, Oxford: Oxbow Books. ISBN 1-900188-64-3

DALES,GEORGE F. (1973) Excavations at Balakot, Pakistan, in the *Journal of Field Archaeology*, Vol. 1, No. 1/2 (1974), pp. 3-22, United States of America, Boston: Boston University
[Accessed 15/06/2009]
http://www.jstor.org/stable/529703

DALES, GEORGE F. and RAIKES, ROBERT L. (1968) The Mohenjo-Daro Floods: A Rejoinder! *In American Anthropologist*, New Series, Vol. 70, No. 5 (Oct., 1968), pp. 957-961, United States of America: Blackwell Publishing on behalf of the American Anthropological Association
http://www.jstor.org/stable/669762

DALLA BONA, LUKE (1994) *Predictive Modelling in Ontario's Forests*, Volume 5: Summary and Recommendations, a report prepared for the Ontario Ministry of Natural Resources, Center for Archaeological Resource Prediction, Thunder Bay, Ontario.
[Accessed: 20/08/2007]
http://modelling.pictographics.com/pdfs/carpvol5.pdf

DALLA BONA, LUKE (2005) Is Archaeological Predictive Modelling a Candidate for the Application of Expert Systems? In *Predictive Modelling for Archaeological Heritage Management: A Research Agenda*, Chapter 11, p.195-204, (Editor) van Leusen, Martijn and Kamermans, Hans, Netherlands, Amersfoort: National Service for Archaeological Heritage, ISBN 90-5799-060-1

DARVILL (2008a) "processual archaeology", in *The Concise Oxford Dictionary of Archaeology*, Oxford Reference Online, United Kingdom, Oxford: Oxford University Press [Accessed 21/06/2009]
http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t102.e3347

DARVILL (2008b) "New Archaeology" in *The Concise Oxford Dictionary of Archaeology*, Oxford Reference Online, United Kingdom, Oxford: Oxford University Press
[Accessed 21/06/2009]
http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t102.e2752

DARVILL (2008c)"post-processual archaeology", in *The Concise Oxford Dictionary of Archaeology*, Oxford Reference Online, United Kingdom, Oxford: Oxford University Press [Accessed 21/06/2009]
http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t102.e3289

DE PUMA, VIMALA (1991) Ceramic Evidence of Pre-Periplus Trade on the Indian Coasts, in *Rome and India*, Chapter 4, p.46, (Editor) Begley, Vimala and De Puma, Richard Daniel, United States of America, Wisconsin, The University of Wisconsin Press, ISBN 0-299-12640-4

DELANEY, DECLAN and BROWN, STEPHEN (2002) Document Templates for Student Projects in *Software Engineering*, Technical Report: NUIM-CS-TR2002-05, August 2002 Ireland, Maynooth: Department of Computer Science, National University of Ireland (Ollcoil na hEireann, Ma Nuad)
[Accessed 27/06/2009]
http://www.cs.nuim.ie/research/reports/2002/nuim-cs-tr-2002-05.pdf

DERRINGER, PAM (2008) Nonprofit chooses Ubuntu for servers, OpenOffice for desktops, 28 May, at *SearchEnterpriseLinux.com*
[Accessed 07/06/2009]
http://searchenterpriselinux.techtarget.com/news/article/0,289142,sid39_gci1315258,00.html

DHAVALIKAR, M. K. and ATRE, SHUBHANGANA (1989) The fire cult and virgin sacrifice: some Harappan rituals, in *Old Problems and New Perspectives in the Archaeology of South Asia*, edited by JonathanMark Kenoyer, 193-205, Wisconsin Archaeological Reports, Vol. 2., United States of America, Wisconsin, Madison, University of Wisconsin, Department of Anthropology: University of Wisconsin Press

DIX, JUSTIN, QUINN, RORY AND WESTLEY, KIERAN (2007) Theme 4 Predictive Modelling of Submerged Archaeological Sites, part of the *Re-assessment of the Archaeological Potential of Continental Shelves Project*, funded by English Heritage's Aggregates Levy Sustainability Fund (ALSF), United Kingdom, Southampton: School of Ocean and Earth Sciences and Department of Archaeology at the University of Southampton
[Accessed 18/09/2007]
http://www.arch.soton.ac.uk/Research/Aggregates/shelve-th4-bk.htm

DRIVER, JONATHON (2006) *Ideas, field names and orginal spreadsheet for zooarchaeological database*, Dr. J. Driver is the client who commissioned zooArc 3.0 (see MATHUR 2006b), Canada, British Columbia, Burnaby: Simon Fraser University, Department of Archaeology

DUDA, R., HART, P.E., NILSSON, N.J., REBOH, R., SLOCUM, J., SUTHERLAND, G. AND GASCHING, JOHN (1974-1983) *Prospector*, United States of America, California, International Menlo Park, Stanford Research Institute (SRI), Artificial Intelligence Center

DUDA, RICHARD O. AND SHORTLIFFE, EDWARD H. (1983), Expert Systems Research, in *Science*, New Series, Vol. 220, No. 4594. (Apr. 15, 1983), pp. 261-268 [Accessed 04/09/2007]
http://www.jstor.org/stable/1690751

DUCKE, BENJAMIN and MUNCH, ULLA (2005) Predictive Modelling and the Archaeological Heritage of Brandenburg, in *Predictive Modelling for Archaeological Heritage Management: A Research Agenda*, Chapter 4, pp. 93-107, (Editor) van Leusen, Martijn and Kamermans, Hans, Netherlands Amersfoort: National Service for Archaeological Heritage, ISBN 90-5799-060-1

DURING CASPERS, E. C. L. (1984) Dilmun: International Burial Ground, in the *Journal of the Economic and Social History of the Orient*, Vol. 27, No. 1 (1984), pp. 1-32, BRILL [Accessed 15/06/2009]
http://www.jstor.org/stable/3631935

DURING CASPERS, E. C. L. (1987) A Copper-Bronze Animal in Harappan Style from Bahrain: Evidence of Mercantile Interaction, in the *Journal of the Economic and Social History of the Orient*, Vol. 30, No. 1 (1987), pp. 30-46, BRILL
[Accessed 06/06/2009]
http://www.jstor.org/stable/3632024

DURING CASPERS, E. C. L. (1991) The Indus Valley 'Unicorn': A Near Eastern Connection? In the *Journal of the Economic and Social History of the Orient*, Vol. 34, No. 4 (1991), pp.312-350, BRILL
[Accessed: 15/06/2009]
http://www.jstor.org/stable/3632455

EBERT, JAMES I. (2000) State of the Art in “Inductive” Predictive Modelling, in *Practical Applications of GIS for Archaeologists: A Predictive Modelling Kit*, Westcott, Konnie L. and Brandon R. Joe, Chapter 8, pp.129-134, United Kingdom, London: Taylor and Francis Ltd., ISBN 0-7484-0830-4

EDENS, CHRISTOPHER (1992) Dynamics of Trade in the Ancient Mesopotamian "World System", in *American Anthropologist*, volume 94, number 1, pages 118--139, Blackwell Publishing on behalf of the American Anthropological Association, ISSN 00027294
[Accessed 14/01/2008]
http://www.jstor.org/stable/680040

EIDEM JESPER and HOJLUND, FLEMMING (1993) Trade or Diplomacy? Assyria and Dilmun in the Eighteenth Century BC, in *World Archaeology*, Vol. 24, No. 3, Ancient Trade: New Perspectives (Feb., 1993), pp. 441-448
Taylor & Francis, Ltd.
[Accessed 15/06/2009]
http://www.jstor.org/stable/124718

EITELJORG II, HARRISON and LIMP, W. FREDRICK (2008)*Archaeological Computing*, Second Edition, Pennsylvania, Bryn Mawr: Center for the Study of Architecture
[Accessed 16/06/2009]
http://archcomp.csanet.org/ftp/outgoing/ArchCompSE.pdf

ELGOOD, HEATHER (2004) Exploring the Roots of Village Hinduism in South Asia, in *World Archaeology*, Vol. 36, No. 3, The Archaeology of Hinduism (Sep., 2004), pp. 326-342, United Kingdom, London: Taylor & Francis Ltd
[Accessed 15/06/2009]
http://www.jstor.org/stable/4128335

ELLIOTT, MARINA (2008) *Craniometric ancestry determination and FORDISC 3.0, MA Theses*, Mentioned by Elliot during public theses presentation, Canada, Burnaby: Simon Fraser University, Department of Archaeology

ENCYCLOPÆDIA BRITANNICA (2009). Early Vedic period, in *Encyclopædia Britannica*
[Accessed 09/06/2009]
http://www.britannica.com/EBchecked/topic/175932/Early-Vedic-period

ESPA, G, BENEDETTI, R, DE MEO, A, RICCI, U. and ESPA, S. (2006) GIS based models and estimation methods for the probability of archaeological site location, in the *Journal of Cultural Heritage*, Volume 7, Issue 3, July-September 2006, Pages 147-155
[Accessed 03/09/2007]
http://www.sciencedirect.com/science/article/B6W6G-4M1VWFS-2/2/2791c68d62fa380d96e4e7740e6ec7e7

ESRI (2005) World Basemap, in *ESRI_World_ES_redmap254243103.zip*
[Accessed 18/05/2005]
http://arcdata.esri.com/data_downloader/DataDownloader?part=10200&s=s&service=ESRI_World&review=1&units=Large&layers=ALL,Country%20Boundaries%203,Water%20Bodies%203,Rivers%203,Streets%20and%20Railroads%201,Boundary%20Lines,B_Major%20Cities%202&minx=67.95685264790274&miny=19.193669647902734&maxx=73.99994735209725&maxy=25.23676435209727&pminx=68.8654298237082&pminy=20.346488&pmaxx=73.09137017629179&pmaxy=24.083946000000005

FAGAN, BRIAN M. (Editor) (1996) "Ur" and "Uruk" in *The Oxford Companion to Archaeology*, Oxford Reference Online, United Kingdom, Oxford: Oxford University Press, ISBN 0195076184
[Accessed 04/07/2009]
http://www.oxfordreference.com/views/ENTRY.html?entry=t136.e0468&srn=1&ssid=634838742#FIRSTHIT
http://www.oxfordreference.com/views/ENTRY.html?entry=t136.e0472&srn=1&ssid=465674551#FIRSTHIT

FALLING RAIN (2009) *Global Gazetteer*
[Accessed 02/02/2009]
http://www.fallingrain.com

FAIRSERVIS, WALTER ASHLIN (1975) *The Roots of Ancient India*, United Kingdom, London: University of Chicago Press Ltd, ISBN 0-226-23429-0

FAIRSERVIS JR., WALTER (1986) Cattle of the Harappan Chiefdoms of the Indus Valley, in *Expedition Magazine*, Volume 28, Number 2, Summer 1986, United States of America, Pennsylvania, Philadelphia, University City: University of Pennsylvania Museum of Archeology and Anthropology, University of Pennsylvania, ISSN 0014-4738
[Accessed 22/06/2009]
http://penn.museum/documents/publications/expedition/PDFs/28-2/Cattle.pdf

FIENNES, R. (1992) *Atlantis of the Sands*, United Kingdom, London: Bloomsbury Publishing, ISBN 0 7475 1327 9

FLETCHER, M. and LOCK, G. (1991) 10 Statistics, in *Archaeology: An Introduction Edition: The History, Principles and Methods of Modern Arcaheology*, Third Fully Revised, by Kevin Greene, 1995 United Kingdom, London: Taylor and Francis Group, Routledge, ISBN 0-203-75544-8

FORD, BEN (2007) Down by the Water's Edge: Modelling Shipyard Locations in Maryland, United States of America, in the *International Journal of Nautical Archaeology* 36 (1), 125–137
[Accessed 03/09/2007]
http://dx.doi.org/10.1111/j.1095-9270.2006.00129.x

FORTE, MAURIZIO and SILIOTTI, ALBERTO (1997) *Virtual Archaeology: Re-Creating Ancient Worlds*, United States of America: Harry N. Abrams, ISBN 0810939436

FRANCFORT, HENRI-PAUL (1983) Excavations at Shortughaï in Northeast Afghanistan, in the *American Journal of Archaeology*, Vol. 87, No. 4 (Oct., 1983), pp. 518-519, United States of America: Archaeological Institute of America
[Accessed 15/06/2009]
http://www.jstor.org/stable/504110

FRAY BOBER, PHYLLIS (1951) Cernunnos: Origin and Transformation of a Celtic Divinity, in the *American Journal of Archaeology*, Vol. 55, No. 1 (Jan., 1951), pp. 13-51, United States of America: Archaeological Institute of America
[Accessed 12/06/2009]
http://www.jstor.org/stable/501179

FROST, KATARINA, JONSSON, KRISTINA and PERSSON, KJELL (2004) The Royal Kitchen Garden at Strömsholm Castle: Evaluating Archaeological Methods, in *Garden History*, Vol. 32, No. 2 (Winter, 2004), pp. 261-271, The Garden History Society
[15/06/2009]
http://www.jstor.org/stable/4150385

FRY, G. L. A., SKAR, B., JERPASEN, G., BAKKESTUEN, V. and ERIKSTAD, L. (2004) Locating archaeological sites in the landscape: a hierarchical approach based on landscape indicators, in *Landscape and Urban Planning*, Volume 67, Issues 1-4, Development of European Landscapes, 15 March 2004, Pages 97-107
(http://www.sciencedirect.com/science/article/B6V91-48CFSFF-1/2/7bb3047b6585418799a7f661145a45f0)

FRITZ, S. (Editor) (2004) *Understanding Artificial Intelligence*, United States of America, New York: Scientific American and Byron Preiss Visual Publications Inc. ISBN 0-446-67875-9.

FULFORD, MICHAEL (1987) Economic Interdependence among Urban Communities of the Roman Mediterranean, in *World Archaeology*, Vol. 19, No. 1, Urbanization, June, pp. 58-75, Published by Taylor & Francis, Ltd
[Accessed 18/04/2008]
http://www.jstor.org/124499

GARDIN, JEAN-CLAUDE et al (1988) Artificial Intelligence and Expert Systems: Case Studies in the Domain of Archaeology, Ellis Horwood Series in *Artificial Intelligence Foundations and Concepts*, United Kingdom, England, West Sussex: Ellis Horwood Ltd., ISBN 0-7458-0431-4

GARDNER, MARTIN (1970) Mathematical Games: The fantastic combinations of John Conway's new solitaire game "life", in *Scientific American*, 223, October, pages 120-123 [Accessed 07/12/2005]
http://ddi.cs.uni-potsdam.de/HyFISCH/Produzieren/lis_projekt/proj_gamelife/ConwayScientificAmerican.htm

GATES, CHARLES (2003) *Ancient cities: the archaeology of urban life in the Ancient Near East and Egypt, Greece and Rome*, reprint, United Kingdom, Abingdon: Routledge, ISBN 0415121825

GAUR, A.S.and SUNDARESH (2003) Onshore excavation at Bet Dwarka Island, in the Gulf of Kachchh, Gujarat, in *Man and Environment*, vol.28(1), 57-66p., India: Indian Society for Prehistoric and Quaternary Studies
[Accessed 04/09/2007]
http://hdl.handle.net/2264/480

GAUR, A.S.and SUNDARESH (2005) A Late Harappan Port at Kindar Kheda on the Saurashtra coast, in *Man and Environment*, vol.30(2), 44-48p., India: Indian Society for Prehistoric and Quaternary Studies
[Accessed 04/09/2007]
http://hdl.handle.net/2264/482

GAUR, A.S., SUNDARESH and PATANKAR, V. (2005) Ancient shell industry at Bet Dwarka island, in *Current Science*, vol. 89(6), 941-946p., India: Indian Academy of Sciences
[Accessed 04/09/2007]
http://hdl.handle.net/2264/334

GAUR, A.S., SUNDARESH and TRIPATI, S. (2005) Ancient Dwarka: Study based on recent underwater archaeological investigations, in *Migration Diffusion*, vol.6(21), 56-77p.
[Accessed 04/09/2007]
http://hdl.handle.net/2264/507

GAUR, A.S., SUNDARESH, TRIPATI, S. and BANDODKAR, S.N. (2005) 'Saurashtra stone anchors' (Ring-stones) from Dwarka and Somnath, west coast of India, in *Puratattva*, vol.32, 131-145p.
[Accessed 04/09/2007]
http://hdl.handle.net/2264/487

GAUR, S. and VORA, K. H. (1999) Ancient shorelines of Gujarat, India, during the Indus civilisation (Late Mid-Holocene): A study based on archaeological evidence, in *Current Science*, July 10th Issue, Article 29, India: Bangalore
[Accessed 08/06/2007]
http://www.infinityfoundation.com/mandala/t_es/t_es_agraw_ships.htm

GEISLER, GARY, VERKERK, DOROTHY, BREIWITZ, KARIN, SPINKS, RICHARD, HAGWOOD, PAUL, TRIPPE, CAROLINE, PATRICK, SCOTT and JOHNSON, HOLLY (1998) Gundestrup Cauldron, in the *catalogue of the Celtic Art and Cultures Website*, United States of America: University of North Carolina
[Accessed 12/06/2009]
http://www.unc.edu/celtic/catalogue/Gundestrup/kauldron.html

GHOSH, A. (Editor) (1990) *An Encyclopaedia of Indian Archaeology*, BRILL, ISBN 9004092641

GIBSON, TERRANCE H. (2005) Off the Shelf: Modelling and Management of Historical Resources, in *Predictive Modelling for Archaeological Heritage Management: A Research Agenda*, Chapter 12, p.209, (Editor) van Leusen, Martijn and Kamermans, Hans, Netherlands Amersfoort: National Service for Archaeological Heritage, ISBN 90-5799-060-1

GODDARD SPACE FLIGHT CENTER (2003) Aqua and Terra Colour and False Colour, Multi-Seasonal 250 m Resolution Satellite Imagery, *NASA MODIS Rapid Response Project*
[Accessed 17/05/2005]
http://rapidfire.sci.gsfc.nasa.gov/gallery/?search=Gujarat&date=

GOKHAL, KEKETAKI (2007) Archaeology News: Indian Americans Spearhead $15M Indus Valley Museum, in *India-West*, Friday 09/11/2007, U.S.A., California, San Leandro: INDIA-WEST PUBLICATIONS, INC., ISSN 0883-721x
[Accessed 16/11/2007]
http://www.indiawest.com/view.php?subaction=showfull&id=1194549345&archive=&start_from=&ucat=1

GOLDBERG, GABRIEL and SMITH, PHILIP H. (1992) *The REXX Handbook*, United States of America: McGraw-Hill, ISBN 0-07-023682-8

GOOGLE EARTH (2005) Google Earth, in *Wikipedia: The Free Encyclopedia*, Wikimedia Foundation, Inc
[Accessed 08/12/2005]
http://en.wikipedia.org/wiki/Google_Earth

GOOGLE EARTH COMPARISON (2005) Google Earth comparison, in *World Wind Central*
[Accessed 08/12/2005]
http://www.worldwindcentral.com/wiki/Google_Earth_comparison#Feature_Comparison

GOWLETT, J.A.J. (1997) High Definition Archaeology: Ideas and Evaluation, in *World Archaeology*, Vol.29, No.2, High Definition Archaeology: Threads through the past, October 1997, pp.152-171, United Kingdom, London: Taylor and Francis Ltd.
[ACCESSED 01/03/2009]
http://www.jstor.org/stable/124945

GRAJETZKI, WOLFRAM, QUIRKE, STEPHEN and SHIODE, NARUSHIGE et al (2000a) Khufu (in Greek 'Kheops'), in *Digital Egypt for Universities: A learning and teaching resource for higher education*, United Kingdom, London: University College London
[Accesed 13/06/2009]
http://www.digitalegypt.ucl.ac.uk/chronology/kingkheops.html

GRAJETZKI, WOLFRAM, QUIRKE, STEPHEN and SHIODE, NARUSHIGE et al (2000b) Kings from Dynasty 0 - Dynasty 2 (before 3000-c 2650 BC), in *Digital Egypt for Universities: A learning and teaching resource for higher education*, United Kingdom, London: University College London
[Accesed 13/06/2009]
http://www.digitalegypt.ucl.ac.uk/chronology/archaic.egypt.kings.html

GREENE, KEVIN (1986) *The Archaeology of the Roman Economy*, United Kingdom, London: B.T. Batsford Ltd, ISBN 0-7134-4593-9

GREENE, KEVIN (1995) *Archaeology: An Introduction Edition: The History, Principles and Methods of Modern Arcaheology*, Third Fully Revised, United Kingdom, London: Taylor and Francis Group, Routledge ISBN 0-203-75544-8

GREENHILL, BASIL (1976) *Archaeology of the boat : a new introductory study*, United States of America, Connecticut, Middletown: Wesleyan University Press, ISBN 0819550027

GRZYMSKI, KRZYSZTOF (2004) Landscape Archaeology of Nubia and Central Sudan, in *The African Archaeological Review*, Vol. 21, No. 1 (Mar., 2004), pp. 7-30, Springer
[15/06/2009]
http://www.jstor.org/stable/25130787

GROTH, ROBERT (1999) Data Mining: Building Competitive Advantage, United States of America, New Jersey: Prentice-Hall Inc, ISBN 0-13-086271-1

GUHA, J.P. (1967) *Seals and Statettes of Kulli, Zhob, Mohenjo Daro, and Harappa*, India, New Delhi-5: Vir Publishing House

GUTH, PETER L. (1999) Quantifying and Visualizing Terrain Fabric from Digital Elevation Models (096), in the *Papers of The IV International Conference on GeoComputation*, hosted by Mary Washington College in Fredericksburg, VA, United States of America, on 25-28 July 1999, Department of Oceanography, U.S. Naval Academy, Annapolis MD 21402-5026
[Accessed 08/12/2005]
http://www.geovista.psu.edu/sites/geocomp99/Gc99/096/gc_096.htm

HAAS, J. (1998) Warfare and the Evolution of Culture, in the *Working Papers of Santa Fe Institute*, Paper 98-10-088, United States of America, The Field Museum, Roosevelt Rd. at Lakeshore Dr., Chicago, IL 60605: Department of Anthropology

HAAS, J. (2001) Interview during television *Horizon* documentary programme, Lost Pyramids of Caral, First aired on BBC Two at 21.00 on Thursday 31 January 2002, accessed via transcript
[Accessed 29/11/2005]
http://www.bbc.co.uk/science/horizon/2001/caraltrans.shtml

HABIB, IRFAN (2001) Imaging River Sarasvati: A Defence of Commonsense, in *Social Scientist*, Vol. 29, No. 1/2 (Jan., 2001), pp. 46-74
[Accessed 29/12/2007]
http://www.jstor.org/stable/3518272

HALL, NEAL (2001) Rossmo sought unit to probe women's deaths: Former Vancouver officer is suing for wrongful dismissal, in the *Vancouver Sun*, Tuesday, June 26, 2001, Canada, Vancouver: Vancouver Sun
[Accessed 05/06/2009]
http://www.missingpeople.net/ex_cop_kim_rossmo_attacks_police_over_missing_women-june_2001.htm

HANNA, MARY (1995) Farewell to waterfalls? - rapid application development - includes product directory, in *Software Magazine*, May 1995, via FindArticles.com. 27 Jun, 2009
[Accessed 27/06/2009]
http://findarticles.com/p/articles/mi_m0SMG/is_n5_v15/ai_17180786/

HANSEN, DAVID T. (2000) Describing GIS Applications: Spatial Statistics and Weights of Evidence Extension to ArcView, Analysis of the Distribution of Archaeology Sites in the Landscape , in the *Proceedings of the Twentieth Annual ESRI International User Conference*, San Diego, CA, July 2000

HANSMAN, JOHN (1973) A "Periplus" of Magan and Meluhha, in the *Bulletin of the School of Oriental and African Studies*, University of London, Vol. 36, No. 3. , pp. 554-587.
[Accessed 11/01/2008]
http://www.jstor.org/stable/613582

HARVEY, BRIAN et al (2008) *Berkley Logo*, United States of America, California: University of Berkely
[Accessed 23/06/2009]
http://www.eecs.berkeley.edu/~bh/

HARVEY, STEVE (2005) Airborne Video Recording - September 2005, Woonona, NSW, *Steve's Aerial Photography Page*
[Accessed 06/12/2005]
http://web.1earth.net/~steveh/aerial.html

HDR (2003) *Final 2003 Study Plan Cooper Lake Project (FERC No. 2170), prepared for Chugach Electric Association Inc.*, April 2003, United States of America, Alaska: HDR Inc. Cultural Resource Consultants
[Accessed 03/08/2007]
http://www.chugachelectric.com/pdfs/relicensing/FinalPlans/CulturalResources_FINAL_4-30-03.pdf

HDR (2005) *Final Proposed Stetson Creek Diversion 2005 Studies Technical Memoranda Cooper Lake Project (FERC No. 2170)*, prepared for Chugach Electric Association Inc., August 2005, United States of America, Alaska: HDR Inc. Cultural Resource Consultants
[Accessed 03/08/2007]
http://www.chugachelectric.com/pdfs/relicensing/StetsonCreek_Diversion_Study_Memos_082605.pdf

HEATON, H A (1939) *History of Trade and Commerce*, Chapter II The Beginnings of Commerce, Page 27, Toronto: Thomas Nelson and Sons Ltd.

HEEHS, PETER (2003) Shades of Orientalism: Paradoxes and Problems in Indian Historiography, in *History and Theory*, Vol. 42, No. 2 (May, 2003), pp. 169-195, United States of America, Connecticut, Middletown: Blackwell Publishing for Wesleyan University
[Accessed 15/06/2009]
http://www.jstor.org/stable/3590880

HENRY, DONALD O. , BAUER, HEATHER A. , KERRY, KRISTOPHER W. , BEAVER, J.JOSEPH E. AND WHITE, JOEL (2001) Survey of Prehistoric Sites, Wadi Araba, Southern Jordan, in the *Bulletin of the American Schools of Oriental Research*, No. 323 (Aug., 2001), pp. 1-19, United States of America, Boston, Boston University: The American Schools of Oriental Research
[Accessed 16/06/2009]
http://www.jstor.org/stable/1357589

HERMAN, C. F. (1996) "Harappan" Gujarat : the Archaeology-Chronology Connection, in *Paléorient- Pluridisciplinary Review of the Prehistory and Protohistory of Southwestern Asia*, Volume 22, Issue 22-2, pp. 77-112, France, Nanterre, Maison Rene Ginouves (CNRS), Maison de l'Archéologie et de l'Ethnologie: Paléorient - Pluridisciplinary Review of the Prehistory and Protohistory of Southwestern Asia
[Accessed 10/06/2009]
http://www.persee.fr/web/revues/home/prescript/article/paleo_0153-9345_1996_num_22_2_4637

HEWITT, KEN (1977) Desertification, Development, and the "Admirals" of Manchar Lake in Sind, Pakistan, in *Economic Geography*, Vol. 53, No. 4, The Human Face of Desertification, The Impact of Desertification (Oct., 1977), pp. 358-363, Clark University
[Accessed 11/01/2008]
http://www.jstor.org/stable/142973

HIMANSHU, PRABHA RAY (1987) Early Historical Urbanization: The Case of the Western Deccan, in *World Archaeology*, Vol. 19, No. 1, Urbanization (Jun., 1987), pp. 94-104, Taylor & Francis, Ltd.
[Accessed 29/01/2009]
http://www.jstor.org/stable/124501

HIMANSHU, PRABHA RAY (2003) *The Archaeology of Seafaring in Ancient South Asia*, United Kingdom, Cambridge: Cambridge University Press, ISBN 0521011094

HIMANSHU, PRABHA RAY (2004) The Beginnings: The Artisan and the Merchant in Early Gujarat, Sixth-Eleventh Centuries, in *Ars Orientalis*, Vol. 34, Communities and Commodities: Western India and the Indian Ocean, Eleventh-Fifteenth Centuries (2004), pp. 39-61,
Freer Gallery of Art, The Smithsonian Institution and Department of the History of Art, University of Michigan
[Accessed 09/06/2009]
http://www.jstor.org/stable/4629607

HIRST, K.K. (2004) Kulli Complex on *About.com* webpage
{Accessed 10/10/2004]
http://archaeology.about.com/library/glossary/bldef_kulli.htm

HOBBS, ELIZABETH, HUDAK, JOSEPH et al (2005) *The Minnesota Archaeological Predictive Model (Mn/Model)*, United States of America, Minnesota: Minnesota Department of Transportation
[Accessed 20/08/2007]
http://www.mnmodel.dot.state.mn.us

HOOKER, JOHN (1996) *The Coriosolite Expert System*
[Accessed 29/05/2006]
http://www.writer2001.com/exp0003.htm

HORN, MICHAEL VAN (1986) *Understanding Expert Systems*, United States of America: Bantam Books Inc., ISBN 0-553-34168-5

HOWARD-CARTER, THERESA (1987) Dilmun: At Sea or Not at Sea?: A Review Article, in the *Journal of Cuneiform Studies*, Vol. 39, No. 1 (Spring, 1987), pp. 54-117, The American Schools of Oriental Research
[15/06/2009]
http://www.jstor.org/stable/1359986

HUTCHINSON, JOSEPH; ALLCHIN, F. R.; VISHNU-MITTRE (1976) India: Local and Introduced Crops [and Discussion], in *Philosophical Transactions of the Royal Society of London*, Series B, Biological Sciences, The Early History of Agriculture, vol 275, no 936, Jul. 27th 1976, pp. 129-141, United Knigdom, London: The Royal Society
[Accessed 01/10/2005]
Stable URL: http://www.jstor.org/stable/2418217

INTERNET ARCHAEOLOGY (2009) *Internet Archaeology*, hosted at the Department of Archaeology at the University of York, United Kingdom: Council for British Archaeology.
[Accesed 20/06/2009]
http://intarch.ac.uk/

INVIS (2003) *AC3D*, Version 4, Invis Ltd.
[Accessed 12/12/20002]
http://www.invis.com

JANSEN, M. (1989) Water Supply and Sewage Disposal at Mohenjo-Daro, in *World Archaeology*, Vol. 21, No. 2, The Archaeology of Public Health (Oct., 1989), pp. 177-192, United Kingdom, London: Taylor and Francis Ltd.
[Accessed 12/06/2009]
http://www.jstor.org/stable/124907

JARRIGE, J.F. and LECHEVALLIER, M. (1977) Excavations at Mehrgarh, Baluchistan: Their Significance, *in South Asian Archaeology*, Prehistoric Context of the Indo-Pakistan Borderlands, (M. Taddei (Editor), pp. 463-535, Italy, Naples: Instituto Universitario Orientale

JARRIGE, J.F. and LECHEVALLIER, M. (1980) Les fouilles de Mehrgahr, Pakistan: problemes chronologiques, in *Paleorient- Pluridisciplinary Review of the Prehistory and Protohistory of Southwestern Asia*, No. 6, pp.253-257, France, Nanterre, Maison Rene Ginouves (CNRS), Maison de l'Archéologie et de l'Ethnologie: Paléorient - Pluridisciplinary Review of the Prehistory and Protohistory of Southwestern Asia

JASC (1998) File Formats Overview: Paintshop Pro Help, Included with *Paintshop Pro 5.03*, United States of America:Jasc Software Inc.

JHA, VIVEKANAND (1991) Social Stratification in Ancient India: Some Reflections, in the *Social Scientist*, Vol. 19, No. 3/4 (Mar. - Apr., 1991), pp. 19-40, Social Scientist
[Accessed 15/06/2009]
http://www.jstor.org/stable/3517554

JOCHIM, MICHAEL A. (1991) Archaeology as Long-Term Ethnography, in *American Anthropologist*, New Series, Vol. 93, No. 2. (Jun., 1991), pp. 308-321.
[Accessed 24/08/2007]
http://www.jstor.org/stable/681297

JOHNSON, GREGORY (1972) A test of the utility of Central Place Theory in Archaeology, in *Archaeology: Theories Methods and Practice*, Forth Edition, by Renfrew, Colin and Bahn, Paul, summary article pp.180-181 by these authors, United Kingdom, London: Thames and Hudson, ISBN 0500284415

JONES, ERIC E. (2006) Using Viewshed Analysis to Explore Settlement Choice: A Case Study of the Onondaga Iroquois, in *American Antiquity*, Vol. 71, No. 3 (Jul., 2006), pp. 523-538
United States of America: Society for American Archaeology
[Accessed 15/06/2009]
http://www.jstor.org/stable/40035363

JONES, S. J. (1947) The Cotton Industry in Bristol, in *Transactions and Papers (Institute of British Geographers)*, No. 13 (1947), pp. 61-79, United Kingdom: Blackwell Publishing on behalf of The Royal Geographical Society (with the Institute of British Geographers)
[Accessed 08/06/2009]
http://www.jstor.org/stable/621146

JSTOR (2009) *Jstor*, United States of America, New York State, New York and Michigan, Ann Arbor
[Accesedd 20/06/2009]
http://www.jstor.org/

KAMPEL, MARTIN and SABLATNIG, ROBERT (2007) Rule based system for archaeological pottery classification, in *Pattern Recognition Letters*, Volume 28, Issue 6, 15 April 2007, Pages 740-747

KAPOOR, ABHISHEK (2004) A civilisation parallel to Harappa? Experts wonder, in *India Exprss*, Ahmedabad Newsline, Sunday , December 12, Page 1, India, Mumbai: Indian Express Newspapers Ltd.
[Accessed 16/11/2007]
http://cities.expressindia.com/fullstory.php?newsid=110070

KEENE, DEREK (2005) Cities and Empires, in the *Journal of Urban History*, Nov 2005; vol. 32: pp. 8 - 21., United States of America, North Carolina, Charlotte: University of North Carolina, ISSN 1552-6771
[Accessed 08/06/2009]
http://juh.sagepub.com/cgi/reprint/32/1/8

KENNEDY, LYNDON and CHANG, SHIH-FU (2008) Internet image archaeology: automatically tracing the manipulation history of photographs on the web, in the *Proceeding of the 16th ACM international conference on Multimedia*, Vancouver, British Columbia, Canada, Applications track A1: tracing table of contents,Pages 349-358, United States of America, New York: ACM, ISBN:978-1-60558-303-7
[Accessed 07/06/2009]
http://doi.acm.org/10.1145/1459359.1459406

KENOYER, J.M. (1997) Trade and Technology of the Indus Valley: New Insights from Harappa, Pakistan, in *World Archaeology*, Vol. 29, No. 2, High Definition Archaeology: Threads through the past, October, p.262-280, United Kingdom, London: Taylor and Francis Ltd., ISBN 00438243
[Accessed 21/02/2009]
http://www.jstor.org/stable/124951

KENOYER, J.M. (2002) Early Developments of Art, Symbol and Technology in the Indus Valley Tradition, at *harappan.com*
[Accessed 12/06/2009]
http://www.harappa.com/indus3/print.html

KENOYER, J.M. (2003) Review of A Peaceful Realm: The rise and fall of the Indus Civilization by Jane R. MacIntosh, Westview Press, Boulder, 2002, in *Asian Perspectives the Journal of Archaeology for Asia and the Pacific* 42(2):376-380, September 22, 2003
[Accessed 21/02/2009]
http://muse.jhu.edu/journals/asian_perspectives/v042/42.2kenoyer01.pdf

KENOYER, J.M. (2005) Culture Change During the Late Harappan Period at Harappa: New Insights on Vedic Aryan Issues, in *The Indo-Aryan Controversy*, (Editor) Bryant, Edwin F. and Paterrn, Laurie L., 2005, United Kingdon, Oxford: Routledge. ISBN 0-700-71462-6

KENOYER, J.M. (2009) Mohenjo-Daro!, at *harappan.com*
[Accessed 16/06/2008]
http://www.mohenjodaro.net/mohenjodarointroduction.html

KENOYER, J.M. and MEADOW, R.H. (2001a) Map of the Indus Era networks, Slide 161, in Around the Indus in 90 Slides 3, slides 115, at *harappa.com*
[Accessed 01/07/2009]
http://www.harappa.com/indus2/161.html

KENOYER, J.M. and MEADOW, R.H. (2001b) Textile impressions from Harappa, Slides 114, 115 and 197, in Around the Indus in 90 Slides 3, slides 115, at *harappa.com*
[Accessed 09/11/2007]
http://www.harappa.com/indus2/114.html
http://www.harappa.com/indus2/115.html
http://www.harappa.com/indus3/197.html

KENOYER, J.M. and MEADOW, R.H. (2001c) Major Periods of Development at Harappa, at *harappa.com*
[Accessed 22/09/2005]
http://www.harappa.com/indus4/e1.html

KENOYER, JONATHAN MARK, VIDALE, MASSIMO AND BHAN, KULDEEP KUMAR (1991) Contemporary Stone Beadmaking in Khambhat, India: Patterns of Craft Specialization and Organization of Production as Reflected in the Archaeological Record, in *World Archaeology*, Vol. 23, No. 1, Craft Production and Specialization (Jun., 1991), pp. 44-63, Taylor & Francis, Ltd.
[Accessed 11/01/2008]
http://www.jstor.org/stable/124728

KERSKI, JOSEPH J. (2004), Unit 9, Lab Exercise: Registering and Using Imagery within a GIS, in *GIS Course*, at Sinte Gleska University: Lakota Studies 400/600: Special Topics: Introduction to Geographic Information Systems and Science, USGS, jjkerski@usgs.gov, 303-202-4315
[Accessed 22/05/2005]
http://rockyweb.cr.usgs.gov/outreach/sgu/imageregistrationlesson.html

KHAN, F.A. (1964) *The Indus Valley and Early Man*, Pakistan, Karachi: The Department of Archaeology and Museums, Ministry of Education, Government of Pakistan

KIRK, WILLIAM (1975) The Role of India in the Diffusion of Early Cultures, in *The Geographical Journal*, Vol. 141, No. 1. (Mar., 1975), pp. 19-34
[Accessed 11/01/2008]
http://www.jstor.org/stable/1796941

KOHLER, T. (1996) Agent-Based Modeling of Anasazi Village Formation in the Northern American Southwest, in the *Working Papers of the Santa Fe Institute*, United States of America: Santa Fe Institute.
[Accessed XX/XX/1996] Link Broken
http://www.santafe.edu/~carr/model/paper.html

KOHLER, Timothy A. (1988) Predictive Location Modelling: History and Current Practice,in *Quantifying the Present and Predicting the Past*, (Editor) Judge, W. and Sebastian, L. pp. 19-58, United States of America, Washington: US Government Printing Office

KOSAMBI, D.D. (1965) *The Culture and Civilisation of Ancient India in Historical Outline*, United Kingdom, London: Routledge and Kegan Paul Ltd.

KOSAMBI, MEERA (1985) Commerce, Conquest and the Colonial City: Role of Locational Factors in Rise of Bombay, in *Economic and Political Weekly*, Vol. 20, No. 1 (Jan. 5, 1985), pp. 32-37, India, Mumbai: Economic and Political Weekly
[Accessed 08/06/2009]
http://www.jstor.org/stable/4373936

KOSAMBI, MEERA and BRUSH, JOHN. E. (1988) Three Colonial Port Cities in India, in *Geographical Review*, Vol. 78, No. 1 (Jan., 1988), pp. 32-47, United States of America, Louisiana, Baton Rouge: American Geographical Society
[Accessed 08/06/2009]
http://www.jstor.org/stable/214304

KRUPP, Dr. E.C. (1978) *In Search of Ancient Astronomies*, United States of America: McGraw-Hill, ISBN 0-07-035556-8

KUHRT, AMÉLIE (1998) *The Old Assyrian Merchants, in Trade, Traders and the Ancient City*, (Editor) Parkins, Helen and Smith, Christopher, United States of America, New York: Routledge, ISBN 0-415-16517-2

KUIPER, JAMES A. and WESCOTT, KONNIE L. (1999) *A GIS Approach for Predicting Prehistoric Site Locations*, July 26-30, United States of America, California, San Diego: Nineteenth Annual ESRI User Conference
[Accessed 24/08/2007]
http://gis.esri.com/library/userconf/proc99/proceed/papers/pap378/p378.htm

KUMAR, MANEESH (2000) Harappan Jewellery, in Archaeology, *Online News*, October 10, 2000, United States of America, New York: Archaeological Institute of America, ISSN 0003-8113
http://www.archaeology.org/online/news/harappa.html

KURZWEIL, RAY (1999) *The Age of Spiritual Machines*, United Kingdom, England: Penguin Books Ltd., ISBN 0670882178

KVAMME, KENNETH L. (1990) One-Sample Tests in Regional Archaeological Analysis: New Possibilities through Computer Technology, *in American Antiquity*, Vol. 55, No. 2. (Apr., 1990), pp. 367-381
[Accessed 03/09/2007]
http://www.jstor.org/stable/281655

LAHIRI, NAYANJOT (1995) Indian Metal and Metal-Related Artefacts as Cultural Signifiers: An Ethnographic Perspective, in *World Archaeology*, Vol. 27, No. 1, Symbolic Aspects of Early Technologies. (Jun., 1995), pp. 116-132
[Accessed 11/01/2008]
http://www.jstor.org/stable/124781

LAHIRI, NAYANJOT (2006) *Finding Forgotten Cities: How the Indus Civilization was Discovered*, United Kingdom, Oxford: Seagull Books, ISBN 1-9054-2-218-0

LAHIRI, NAYANJOT and BACUS, ELISABETH A. (2004) Exploring the Archaeology of Hinduism, in *World Archaeology*, Vol. 36, No. 3, The Archaeology of Hinduism (Sep., 2004), pp. 313-325 United Kingdom, London: Taylor & Francis Ltd
[Accessed 15/06/2009]
http://www.jstor.org/stable/4128334

LAL, B.B. (2005) Aryan Invasion of India: Perpetuation of a Myth, in *The Indo-Aryan Controversy*, (Editor) Bryant, Edwin F. and Paterrn, Laurie L., 2005, United Kingdon, Oxford: Routledge, ISBN 0-700-71462-6.

LAMBERG-KARLOVSKY, C.C. (1972) Trade Mechanisms in Indus-Mesopotamian Interrelations, in the *Journal of the American Oriental Society*, Vol. 92, No. 2, April-June, p.222-229, American Oriental Society, ISBN 00030279
http://www.jstor.org/stable/600649

LAMBERG-KARLOVSKY, C.C. (1975) Third Millenium Exchange and Production, in *Ancient Trade and Civilisation* by Sabloff, Jeremy, A. and Lamberg-Karlovsky, C.C., 1975, United States of America: American School of Research, ISBN 0826303455

LAMBOURN, ELIZABETH (2002) The English Factory or Kothi Gateway at Cambay: An Unpublished Tughluq Structure from Gujarat, in the *Bulletin of the School of Oriental and African Studies*, University of London, Vol. 65, No. 3 (2002), pp. 495-517, United Kingdom, Cambridge: Cambridge University Press on behalf of School of Oriental and African Studies
[Accessed 08/06/2009]
http://www.jstor.org/stable/4146030

LAMBRICK, H. T. (1967) The Indus Flood-Plain and the 'Indus' Civilization, in the *Geographical Journal*, Vol. 133, No. 4 (Dec., 1967), pp. 483-495, United Kingdom: Blackwell Publishing on behalf of The Royal Geographical Society (with the Institute of British Geographers)
[Accessed 15/06/2009]
http://www.jstor.org/stable/1794477

LAMPE, KARL-HEINZ, KOENIG, ALEXANDER and RIEDE, KLAUS (2008) Research between natural and cultural history information: Benefits and IT-requirements for transdisciplinarity, in the *Journal on Computing and Cultural Heritage (JOCCH) archive*, Volume 1 , Issue 1 (June 2008) table of contents, Article No. 4, United States of America, New York: ACM, ISSN:1556-4673
[Accessed 07/06/2009]
http://doi.acm.org/10.1145/1367080.1367084

LAURIERE, J.L. (1988) Foreword, in *Artificial Intelligence and Expert Systems: Case Studies in the Domain of Archaeology*, by Gardin, Jean-Claude, Ellis Horwood Series in Artificial Intelligence Foundations and Concepts, United Kingdom, England, West Sussex: Ellis Horwood Ltd., ISBN 0-7458-0431-4

LAWLER, ANDREW (2008) Boring No More, a Trade-Savvy Indus Emerges, in *Science*, New Series, Vol. 320, No. 5881 (Jun. 6, 2008), pp. 1276-1281, United States of America: American Association for the Advancement of Science
[Accessed 15/06/2009]
http://www.jstor.org/stable/20054862

LIEBERMAN, STEPHEN J. (1980) Of Clay Pebbles, Hollow Clay Balls, and Writing: A Sumerian View, in the *American Journal of Archaeology*, Vol. 84, No. 3 (Jul., 1980), pp. 339-358, United States of America: Archaeological Institute of America
[Accessed: 21/06/2009]
http://www.jstor.org/stable/504711

LESHNIK, S.LAWRENCE (1968) The Harappan "Port" at Lothal: Another View, in *American Athropologist*, New Series, Vol. 70, No. 5, Oct,. 1968, pp. 911-922, United States of America: Blackwell Publishing on behalf of the American Anthropological Association
[Accessed 01/01/2005]
http://www.jstor.org/stable/669756

LEWIS, Sir GEORGE CORNEWALL (1862) *Astronomy of the Ancients*, United Kingdom, London, West Strand: Parker, Son and Bourn

LOWE, ANTHONY (1986) Bronze Age Burial Mounds on Bahrain, in *Iraq*, Vol. 48, (1986), pp. 73-84, British Institute for the Study of Iraq
[Accessed 15/06/2009]
http://www.jstor.org/stable/4200252

McALLISTER, MICK (1989) *Illustrated Turbo Prolog 2.0*, United States of America, Texas: Wordware Publishing Inc., ISBN 0-915381-97-4

McCARTHY, JOHN, ABRAHAMS, PAUL W. , EDWARDS, DANIEL J. , HART, TIMOTHY P. and LEVIN, MICHAEL I. (1962) *LISP 1.5 Programmer's Manual*, second edition, United States of America, Massachusetts: Massachusetts Institute of Technology Press
[Accessed 23/06/2009]
http://www.softwarepreservation.org/projects/LISP/book/LISP 1.5 Programmers Manual.pdf

McGRAIL, S.(2001) *Boats of The World: From The Stone Age To Medieval Times*, United Kingdom, Oxford: OUP, ISBN 0198144687

McGUIRE, RANDALL H. (1992) *Marxist Archaeology*, United States of America, California, San Diego: Academic Press Limited. ISBN 0-12-484078-7.

McINTOSH, JANE R. (2002) *A Peaceful Realm: The rise and fall of the Indus Civilization*, United States of America, Boulder,.Colorado: Westview Press

MCINTOSH, JANE and WEEKS, JOHN M. (2007) *The Ancient Indus Valley: New Perspectives*, First Edition, 15 June 2007, United States of America, California, Santa Barbara: ABC-CLIO, ISBN 9781576079072

MCINTOSH, RODERICK J. (1996) "History of Archaeology, Intellectual", in *The Oxford Companion to Archaeology*, Brian M. Fagan, ed., Oxford Reference Online, United Kingdom, Oxford: Oxford University Press
[Accessed 21/06/2009]
http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t136.e0188

MACKAY, ERNEST JOHN HENRY (1935) *The Indus Civilization*, Originally published United Kingdom, London: L. Dickson and Thompson, Reprint United Kingdom, York: AMS Press in 1983, ISBN 0404166733

MACKIE, QUENTIN (1998) *The Archaeology of Fjordland Archipelagos: mobility networks, social practice and the built environment*, PhD Thesis, United Kingdom, Southampton: University of Southampton, Department of Archaeology
[Accessed 03/09/2007]
http://eprints.soton.ac.United Kingdom/43756/01/0000366.pdf

MacQUEEN, KEN and MACDONALD, NANCY (2007) Strong Evidence against Robert Pickton in Trial, in *Maclean's* February 5, 2007, Canada: Macleans
[Accessed 05/06/2009]
http://www.canadianencyclopedia.ca/index.cfm?PgNm=TCE&Params=M1ARTM0013077

MAHADEVAN, IRAVATHAM (1977) The Indus Script: Texts, Concordance and Tables, in *Memoirs of the Archaeological Survey of India*

MAHADEVAN, IRAVATHAM (1997) *An Encylopaedia of the Indus Script*, in International Journal of Dravidian Linguistics, January, India, Trivandrum

MALVILLE, J. McKIM and PUTNAM, CLAUDIA (1989) *Prehistoric Astronomy in the South West*, United States of America, Colorado, Boulder: Johnson Publishing Company, ISBN 1-55566-041-X

MARSHALL CAVENDISH (1969) *Cradles of Civilisation*, Marshall Cavendish Books Ltd.

MARSHALL, J. (editor) (1931) *Mohenjo-daro and the Indus Civilization Volume I-III*, India, New Delhi: Asian Educational Services, Reprint 1996

MASCHNER, H. D. G. and STEIN, J. W. (1995) Multivariate approaches to site location on the Northwest Coast of North America, in *Antiquity*, Vol. 68; Number 262, pages 61-73, United Kingdom, Oxford: Antiquity Publications, ISSN 0003-598X
[Accessed 24/08/2007]
http://www.antiquity.ac.uk/Ant/069/0061/Ant0690061.pdf

MATH WORKS, THE (2007) *Matlab R2007b*, version 7.5.0.342 (R2007b)

MATHUR, ROY (1995) *The Analysis of MODES and the Specification of ORES for Bromley Museum*, MSc Dissertation, Volume 1 of 3, United Kingdom, London: University of Westminster

MATHUR, ROY (2006a) *ORES 2.0, Object Retreival/Entry System*, Software, Canada, Alberta, East Coulee: Sand Dune Cat Archaeological Consulting

MATHUR, ROY (2006b) *zooArc 3.0*, zooarchaeological database software as described in the zooArc help file (zooarc.txt), Canada, British Columbia, Vancouver: Sand Dune Cat Archaeological Consulting

MATHUR, ROY (2008) GIS-Based Regional Analysis: Predictive Modeling of the Indus Civilization Port Sites in the Gujarat: Site Location Through Rules-Based Predictive Modeling, in Clark, Jeffrey T., Emily M. Hagemeister (Editors): *Digital Discovery: Exploring New Frontiers in Human Heritage*, CAA 2006, Computer Applications and Quantitative Methods in Archaeology, Proceedings of the 34th Conference, Fargo, United States, April 2006, 215-225, Budapest: Archaeolingua, ISBN 978-963-8046-90-1 [Accessed 08/07/2009]
http://www.leidenuniv.nl/caa/proceedings/caa_2006_proceedings.htm

MATTINGLY, DAVID J. and SALMON, JOHN (Editor) (2001) *Economies Beyond Agriculture in the Classical World*, p.5, United Kingdom, London: Routledge, ISBN 0-415-21253-7

MEHRER, MARK and WESCOTT, KONNIE (2005) *GIS and Archaeological Site Location Modeling*, United States of America: Taylor and Francis, CRC Press, ISBN 9780415315487

MILLER, J. INNES (1969) *The Spice Trade of the Roman Empire, 29 B.C. to A.D. 641*, United Kingdom, Oxford: Clarendon Press

MINNESOTA, STATE OF (2007) Just the Facts, on the *State of Minnesota Government Website*, United States of America, Minnesota: Government of Minnesota
[Accessed 03/09/.2007]
http://www.state.mn.us/portal/mn/jsp/content.do?id=-8542&subchannel=null&sc2=null&sc3=null&contentid=536879492&contenttype=EDITORIAL&programid=536888179&agency=NorthStar

MIT EDUCATION (2005) *StarLogo On The Web*, United States of America, Massachusetts: Massachusetts Institute of Technology
[Accessed 11/11/2005]
http://education.mit.edu/starlogo/

MITHEN, STEVEN J. (2003) *After the ice : A Global Human History, 20,000-5000 BC*, United Kingdom, London: Weidenfeld & Nicolson, ISBN 0297643185

MITTER, PARTHA (1986) The Early British Port Cities of India: Their Planning and Architecture Circa 1640-1757, in *The Journal of the Society of Architectural Historians*, Vol. 45, No. 2 (Jun., 1986), pp. 95-114, United States of America, Virginia, Charlottesville: University of Virginia Press
Society of Architectural Historians
[Accessed 08/06/2009]
http://www.jstor.org/stable/990090

MODELSKI, GEORGE (1997) Cities of the Ancient World: An Inventory (-3500 to -1200), in *The Evolutionary World Politics Homepage*, July 10 1997, United States of America, Washington: University of Washington, Department of Political Science
[Accessed 22/06/2009]
https://faculty.washington.edu/modelski/WCITI2.html

MOLER, STEVE (1981) *MATLAB Users' Guide*, June, 25th 1981, United States of America, New Mexico: Department of Computer Science, University of New Mexico

MOON, HEATHER (1993) Resources Inventory Committee Report 016 Discussion Document, Aril 30, Archaeological Predictive Modelling: An Assessment, Chapter 4 Archaeological Applications of Geographical Information Systems in *Cultural Resource Management*, p.15, Submitted to the RIC by Moon, H. of the Archaeology Task Group of the Earth Sciences Task Force, Archaeology Branch, Ministry of Tourism and Ministry Responsible for Culture, RIC: Victoria, BC, Canada

MORBY, JOHN E. (2002) "Mesopotamia, Early", in *Dynasties of the World*, Oxford Reference Online, United Kingdom, Oxford: Oxford University Press
[Accessed 04/07/2009]
http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t130.e157

MORLEY, NEVILLE (2007) *Trade in Classical Antiquity: Key Themes in Ancient History*, United Kingdom, Cambridge: Cambridge University Press, ISBN 978-0-521-63279-9

MORRIS, IAN (1991) *The Early Polis as City and State, in City and Country in the Ancient World*, United Kingdom, London: Routledge, ISBN 0-415-01974-5

MORRISON, KATHLEEN D. (1997) Commerce and Culture in South Asia: Perspectives from Archaeology and History, in the *Annual Review of Anthropology*, Vol. 26, (1997), pp. 87-108, Annual Reviews
[15/06/2009]
http://www.jstor.org/stable/2952516

MORTAZAVI, MEHDI (2005) Economy, Environment and the Beginnings of Civilization in Southeastern Iran, in *Near Eastern Archaeology*, Vol. 68, No. 3, Archaeology in Iran (Sep., 2005), pp. 106-111, The American Schools of Oriental Research
[15/06/2009]
http://www.jstor.org/stable/25067608

MULCHANDANI, ANIL (1998) The Indus Valley Civilisation at Lothal, at *harappa.com*
[Accessed 09/06/2003]
http://www.harappa.com/lothal/text.html

MURPHY, DAVE (2005) Unraveling the life of a little mummy: CT scans help scientists delve into preserved body of girl born about same time as Jesus, in *San Francisco Chronicle*, Thursday, August 4, 2005, United States of America, San Francisco: San Francisco Chronicle
[Accessed 01/01/2005]
http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2005/08/04/MUMMY.TMP

MURRANT, JAMES (1995) *The Boating Bible*, Australia, Sydney: Harper Collins, ISBN 0 207 16166 6

MURPHY, KEVIN (2000) In praise of Bayes, in *The Economist*, September 30th 2000
[Accessed 03/09/2007].
http://www.cs.ubc.ca/~murphyk/Bayes/economist.html

NASA AMES RESEARCH CENTER (2004) *World Wind Features*, Learning Technologies, United States of America: NASA
[Accessed 08/12/2005]
http://worldwind.arc.nasa.gov/features.html

NASH, JOHN F. (1950) Equilibrium Points in N-Person Games, in the *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 36, No. 1. (15 January 1950), pp. 48-49.

NATIONAL GEOSPATIAL INTELLIGENCE AGENCY (2003a) *NGIA Raster Roam*, United States of America, Bethesda: NGA
[Accessed 08/12/2005]
http://geoengine.nga.mil/geospatial/SW_TOOLS/NIMAMUSE/webinter/rast_roam.html

NATIONAL GEOSPATIAL INTELLIGENCE AGENCY (2003b) *Digital Terrain Elevation Data*, United States of America, Bethesda: NGA
[Accessed 08/12/2005]
https://www1.nga.mil/ProductsServices/TopographicalTerrestrial/DigitalTerrainElevationData/Pages/default.aspx

NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY (2009) National Intelligence Mapping Agency, country data for India, elevation data in *in_rg.zip* compressed archive file containing in.txt, United States of America, Bethesda: NGA
[Accessed 29/01/2009]
http://earth-info.nga.mil/gns/html/cntyfile/in_rg.zip

NATIONAL OCEANOGRAPHY AND ATMOSPHERIC ADMINISTRATION (2009) *World palaeoclimatology data*, United States of America: National Climatic Data Center, NOAA Paleoclimatology
[Accessed 08/12/2005]
http://www.ncdc.noaa.gov/paleo/

NATIONALMUSEET (2009) Gundestrup Cauldron, in Danish Prehistory at the *National Museum of Denmark*, Denmark, Copenhagen: Nationalmuseet
[Accessed 12/06/2009]
http://www.nationalmuseet.dk/sw33830.asp

NETLOGO (2009) *NetLogo Homepage*, United States of America, Northwestern University: The Center for Connected Learning (CCL) and Computer-Based Modeling
[Accessed 23/06/2009]
http://ccl.northwestern.edu/netlogo/

NEUFIELD, DERRICK J. and GRIFFITH, SCOTT (2006) Isobord's Geographic Information System (GIS) Solution, in *Cases on Database Technologies and Applications* by Khosrow-Pour, Mehdi, United Kingdom, London: Idea Group Publishing, ISBN 1-59904-399-8

NEUGEBAUER, OTTO (1975) *A History of Ancient Mathematical Astronomy*, Vol. 1 of 3, Germany, Berlin: Springer-Verlag, ISBN 0-387-06995-X

NHK (2000) *The Indus: The Unvoiced Civilisation*, produced by Shigenobu, Yutaka, directed by Nagasawa, Tomeni for NHK (NHK ENTERPRISES 21) in Japan, half hour programme screened by Channel 4 United Kingdom c.2006, video recording of above published by United States of America, Princeton, New Jersey: Film for Humanities and Sciences 2001, ISBN 0736534776

OFFICE OF GOVERNMENT COMMERCE (OGC) (2001) *Business Systems Development with SSADM CD-ROM*, United Kingdom: The Stationery Office (TSO) , ISBN 9780113308842

OPENARCHAEOLOGY.NET (2009) *OpenArchaeology.net*
[Accessed 07/06/2009]
http://openarchaeology.net/contents/about

ORMSBY, TIM et al (2001) Getting to Know ArcGIS Desktop, United States of America, California, Redlands: ESRI. ISBN 1-879102-89-7

ORTON, NANCY PINTO (1991) Red Polished Ware in Gujarat: A Catalogue of Twelve Sites, in *Rome and India*, Chapter 4, p.46 by Begley, Vimala and De Puma, Richard Daniel, United States of America, Wisconsin: University of Wisconsin Press, ISBN 0-299-12640-4

OUSLEY, S.D. AND JANTZ, R.L. (2005) *FORDISC 3.0 Personal Computer Forensic Discriminant Functions*, United States of America, Tennessee: The University of Tennessee, Forensic Anthropology Center

OXFORD ARCHAEOLOGY (2009) "Open Office", in *Open Source We Use (or Like)*, United Kingdom, Oxford: Oxford Archaeology
[Accessed 06/07/2009]
http://thehumanjourney.net/index.php?option=com_content&task=view&id=157&Itemid=179

PARKER, BRADLEY J. (2003) Archaeological Manifestations of Empire: Assyria's Imprint on Southeastern Anatolia, in the *American Journal of Archaeology*, Vol. 107, No. 4 (Oct., 2003), pp. 525-557, United States of America: Archaeological Institute of America
[Accessed 15/06/2009]
http://www.jstor.org/stable/40024322

PARKER, DAWN C., MANSON, STEVEN M., JANSSEN, MARCO A., HOFFMANN, MATTHEW J. and DEADMAN, PETER (2003) Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review, in the *Annals of the Association of American Geographers*, Vol. 93, No. 2 (Jun., 2003), pp. 314-337, United Kingdom, London: Taylor & Francis, Ltd. on behalf of the Association of American Geographers
[Accessed 15/06/2009]
http://www.jstor.org/stable/1515560

PARPOLA, ASKO (1986) The Indus Script: A Challenging Puzzle, in *World Archaeology*, vol. 17, No. 3, Early Writing Systems, February, p. 399-419, United Kingdom: Routledge and Kegan Paul Ltd.
[Accessed 06/12/2005]
http://www.jstor.org/stable/124704

PARPOLA, ASKO (1994) Deciphering the Indus Script, United Kingdom, Cambridge: Cambridge University Press

PARPOLA, ASKO (1994) *Deciphering the Indus Script*, United Kingdom, Cambridge: Cambridge University Press

PARPOLA, ASKO AND JOSHI, J.P. (1987) *Corpus of Indus Seals and Inscriptions*, vol. I Collections in India, Helsinki

PARPOLA, ASKO and SHAH, S.G.M. (1991) *Corpus of Indus Seals and Inscriptions*, vol. II Collections in Pakistan, Helsinki

PARPOLA, SIMO (1993) The Assyrian Tree of Life: Tracing the Origins of Jewish Monotheism and Greek Philosophy, in *Journal of Near Eastern Studies*, Vol. 52, No. 3. (Jul., 1993), pp. 161-208.
[Accessed 11/01/2008]
http://www.jstor.org/stable/545436

PARPOLA, SIMO, PARPOLA, ASKO and BRUNSWIG Jr, ROBERT H. (1977) The Meluhha Village: Evidence of Acculturation of Harappan Traders in Late Third Millennium Mesopotamia? In the *Journal of the Economic and Social History of the Orient*, Vol. 20, No. 2 (May, 1977), pp. 129-165, BRILL
[Accessed 06/06/2009]
http://www.jstor.org/stable/3631775

PEREGRINE, PETER N. (2001) Cross-Cultural Comparative Approaches in Archaeology, in the *Annual Review of Anthropology*, Vol. 30, (2001), pp. 1-18
Annual Reviews
[15/06/2009]
http://www.jstor.org/stable/3069206

PEREGRINE, PETER N. AND EMBER, MELVIN (editors) (2003) *Encyclopedia of Prehistory*, Volume 8: South and Southwest Asia, 415 p., hardcover, United States of America, Connecticut, City of New Haven: Human Relations Area Files Inc
ISBN: 978-0-306-46262-7

PERKINS, ANN and BRAIDWOOD, ROBERT J. (1947) Archaeological News, in *American Journal of Archaeology*, Vol. 51, No. 4. (Oct. - Dec., 1947), pp. 419-431.
[Accessed 11/01/2008]
http://www.jstor.org/stable/500755

PETRUSO, KARL M. (1981) Early Weights and Weighing in Egypt and the Indus Valley, in the *M Bulletin (Museum of Fine Arts, Boston)*, Vol. 79, (1981), pp. 44-51, United >States of America, Boston: Museum of Fine Arts, Boston
[Accessed 14/06/2009]
http://www.jstor.org/stable/4171634

PIDOT JUNIOR, GEORGE B. and SOMMER, JOHN W. (1974) *Modal Cities*, EPA-600/5-74-027, October, United States of America, Washington: Office of Research and Development, U.S. Environmental Protection Agency, Washington D.C. 20460

PODOBNIKAR, TOMAZ, VELJANOVSKI, TATJANA, STANCIC, ZORAN and OSTIR, KRISTOF (2000)
Archaeological Predictive Modelling for Highway Construction Planning, in *Proceedings of the 28th CAA conference*, held at Ljubljana, Slovenia,18-21 April 2000, Edited by Zoran Stancic and Tatjana Veljanovski, United Kingdom, Oxford: Published in the BAR International Series 931, Archaeopress, 2001
[Accessed 04/06/2009]
http://www.lania.mx/~ccoello/costelloe01.pdf.gz

POLAK, H.S.L. (1930) The Salt March: Toward Dandi, in *The Gandhi Reader: A Sourcebook of His Life and Writings*, by Jack A. Homer, Chapter 10, Revised edition (January 5, 1994), United States of America, New York: Grove Press, ISBN 978-0802131614

POSSEHL, GREOGORY L. (1967) The Mohenjo-daro Floods: A Reply, in *American Anthropologist*, New Series, Vol. 69, No. 1 (Feb., 1967), pp. 32-40, United States of America: Blackwell Publishing on behalf of the American Anthropological Association
[Accessed 12/06/2009]
http://www.jstor.org/stable/670484

POSSEHL, GREOGORY L. (1975) Review of Lothal and the Indus Valley Civilisation by S.R. Rao, in the *Journal of the American Oriental Society*, Vol. 95, No. 1 (Jan. - Mar., 1975), pp. 164-165, United States of America: American Oriental Society
[Accessed 26/07/2008]
http://www.jstor.org/stable/599318

POSSEHL, GREOGORY L. (1986) Rojdi: The Investigation of a Prehistoric Town in India, in *American Journal of Archaeology*, Vol. 90, No. 4 (Oct., 1986). 467-468, United States of America: Archaeological Institute of America
[Accessed 07/05/2009]
http://www.jstor.org/stable/506035

POSSEHL, GREOGORY L. (1990) Revolution in the Urban Revolution: The Emergence of Indus Urbanization, in *Annual Review of Anthropology*, Vol. 19 (1990), pp. 261-282, United States of America, Philadelphia: University of Pennsylvania
[Accessed 29/12/2007]
http://www.jstor.org/stable/2155966

POSSEHL, GREGORY L. (1996) *The Indus Age: The Writing System*, United States of America, Philadelphia: University of Pennsylvania Press

POSSEHL, GREGORY L (1997) The transformation of the Indus Civilization, in *Journal of World Prehistory*, Volume 11, Number 4 / December, 1997, pp. 425-472, Netherlands: Springer, ISSN 1573-7802 (Online)
[Accessed 10/06/2009]
http://www.springerlink.com/content/pr321t6776416581/fulltext.pdf

POSSEHL, GREOGORY L. (1999) *Indus Age : The Beginnings*, United States of America, Philadelphia: University of Pennsylvania Press, ISBN 0812234170

POSSEHL, GREOGORY L. (2002) *The Indus Civilisation: A Contemporary Perspective*, United States of America, California, Walnut Creek: Altamira Press, ISBN 0-7591-0172-8

POSSEHL, GREGORY L. and KENNEDY, KENNETH A. R (1979) Hunter-Gatherer/Agriculturalist Exchange in Prehistory: An Indian Example, in *Current Anthropology*, Vol. 20, No. 3 (Sep., 1979), pp. 592-593, United States of America, Chicago: The University of Chicago Press on behalf of Wenner-Gren Foundation for Anthropological Research
[Accessed 29/01/2009]
http://www.jstor.org/stable/2742123

POTTER, DAVID S. (Editor) (2006) *A Companion to the Roman Empire*, United Kingdom, Oxford: Blackwell Publishing Ltd., ISBN 978-0-631-22644-4

POTTS, D. T. (1985) Reflections on the History and Archaeology of Bahrain (in Review Article), in the *Journal of the American Oriental Society*, Vol. 105, No. 4. (Oct. - Dec., 1985), pp. 675-710, United States of America: American Oriental Society
[Accessed 17/04/2009]
http://www.jstor.org/stable/602727

POTTS, D.T. (1993) Rethinking Some Aspects of Trade in the Arabian Gulf, in *World Archaeology*, Vol.24, No.3, Ancient Trade: New Perspectives, (Feb.,1993), pp.423-440, United Kingdom, London: Taylor & Francis Ltd.
[Accessed 17/04/2009]
http://www.jstor.org/stable/124717

POTTS, T.F. (1993) Patterns of Trade in Third-Millennium BC Mesopotamia and Iran, in *World Archaeology*, Vol.24, No.3, Ancient Trade: New Perspectives, (Feb.,1993), pp.379-402, United Kingdom, London: Taylor & Francis Ltd.
[Accessed 17/04/2009]
http://www.jstor.org/stable/124715

PRUTHI, RAJ (2004) *Prehistory and Harappan Civilization*, India, New Delhi: A.P.H. Publishing Corp., ISBN 8176485810

PRINGLE, HEATHER (2001) The First Urban Center in the Americas, in *Science*, 27 April 2001: Vol. 292. no. 5517, p. 621

RACKHAM, JAMES (1994) *Animal Bones*, United Kingdom, London: British Museum Press. ISBN 0-7141-2057-X

RAIKES, ROBERT L. (1964) The End of the Ancient Cities of the Indus, in *American Anthropologist*, New Series, Vol. 66, No. 2 (Apr., 1964), pp. 284-292+294-299, Blackwell Publishing on behalf of the American Anthropological Association
[Accessed 15/06/2009]
http://www.jstor.org/stable/669009

RAIKES, ROBERT L. and DYSON, ROBERT H. (1961) The Prehistoric Climate of Baluchistan and the Indus Valley, in the *American Anthropologist*, New Series, Vol. 63, No. 2, Part 1. (Apr., 1961), pp. 265-281, United States of America: AmericanAnthropologicalAssociation
[Accessed 11/01/2008]
http://www.jstor.org/stable/667527

RAO, RAJESH (2009) *Analysis of the 4500-year-old Indus Script, Abstract*, United States of America, Washington: University of Washington
[Accessed 07/06/2009]
http://www.cs.washington.edu/homes/rao/

RAO, S.R (1973) *Lothal and the Indus Civilisation*, Bombay: G. G. Pathere at Popular Press Ltd, ISBN 0210222786

RAO, S.R. (1979) Lothal: A Harappan Port Town (1955-1962), Memoirs of the Archaeological Survey of India, No. 78, Vol. 1 (1979), Vol. 2 (1985), India: New Delhi: Director General of the Archaeological Survey of India

RAPOPORT, ANATOL, CHAMMAH, ALBERT M. and ORWANT, CAROL J. (1965) *Prisoner's Dilemma*, Contributor Albert M. Chammah, Edition: 2, illustrated, Published by University of Michigan Press, ISBN 0472061658, 9780472061655 270 pages

RATNAGAR, SHEREEN (2001) The Bronze Age Unique Instance of a Pre-Industrial World System? In *Current Anthropology*, Volume 42, Number 3, June, The Wenner-Gren Foundation for Anthropological Research. All rights reserved
[Accessed 29/01/2009]
http://www.journals.uchicago.edu/doi/pdf/10.1086/320473

RATNAGAR, SHEREEN (2004) *Trading Encounters: from the Euphrates to the Indus in the Bronze Age*, Oxford: OUP. ISBN 0195666038.

REEVES, DACHE M. (1936) Aerial Photography and Archaeology, in *American Antiquity*, Vol 2 of 2, October, Society for American Archaeology
[Accessed 06/12/2005]
http://www.jstor.org/stable/275881

READE, JULIAN (2001) Assyrian King-Lists, the Royal Tombs of Ur, and Indus Origins, in the *Journal of Near Eastern Studies*, Vol. 60, No. 1 (Jan., 2001), pp. 1-29, United States of America, Chicago: University of Chicago Press
[Accessed 15/06/2009]
http://www.jstor.org/stable/545577

REITZ, ELIZABETH and WING, ELIZABETH, S. (1999) *Zooarchaeology*,
United Kingdom, Cambridge: Cambridge University Press, ISBN 0 521 48069 8.

RENFREW, COLIN and BAHN, PAUL (2004) *Archaeology: Theories Methods and Practice*, Forth Edition, United Kingdom, London: Thames and Hudson, ISBN 0500284415

RENFREW, COLIN and BAHN, PAUL (Editors) (2005) *Archaeology: The Key Concepts*, United Kingdom, London: Taylor and Francis Group, Routledge, ISBN 0-415-31757-6.

RESNICK, MITCHEL (1994) *Turtles, Termites and Traffic Jams*, United States of America, Cambridge, Massachusetts: Massachusetts Institute of Technology Press, ISBN 0262181622

RICHARDS, J.D. and RYANS, N.Y. (1985) *Data Processing in Archaeology*, United Kingdom, Cambridge: Cambridge University Press, ISBN 0-521-25769-7

RISSMAN, PAUL (1988) Public Displays and Private Values: A Guide to Buried Wealth in Harappan Archaeology, in *World Archaeology*, Vol. 20, No. 2, Hoards and Hoarding (Oct., 1988), pp. 209-228, Taylor & Francis, Ltd.
[Accessed 06/06/2009]
http://www.jstor.org/stable/pdfplus/124471.pdf

ROSSITER, D.G. and HENGL, T. (2002) *Technical note: Creating geometrically-correct photo-interpretations, photomosaics, and base maps for a GIS project, version with figures*, 3rd Revised Version, 26th March, International Institute for Geo-Information Science and Earth Observation, Soil Science Division
[Accessed 10/12/2005]
http://www.itc.nl/~rossiter/teach/lecnotes.html

ROSSMO, KIM (2009) *Resume*, United States of America, Texas: Texas State University, Center for Geospatial Intelligence and Investigation
[Accessed 05/06/2009]
http://www.txstate.edu/gii/documents/RossmoResume.doc

ROWTON, M. B. (1958) The Date of Hammurabi, in the *Journal of Near Eastern Studies*, Vol. 17, No. 2 (Apr., 1958), pp. 97-111, United States of America, Chicago: The University of Chicago Press
[Accessed 06/06/2009]
http://www.jstor.org/stable/542616

ROUX, V., BRIL, B. and DIETRICH, G. (1995) Skills and Learning Difficulties Involved in Stone Knapping: The Case of Stone-Bead Knapping in Khambhat, India, in *World Archaeology*, Vol. 27, No. 1, Symbolic Aspects of Early Technologies (Jun.), pp. 63-87, Taylor & Francis, Ltd.
[Accessed 29/01/2009]
http://www.jstor.org/stable/124778

RSNA (2005) Computed Tomography (CT) – Body, at r*adiologyinfo.org*, United States of America: Radiological Society of North America, Inc.
[Accessed 21/10/2005]
http://www.radiologyinfo.org/content/ct_of_the_body.htm

RUBIO, JUAN LUCAS DOMÍNGUEZ (2009) Sqlite & Nokia join the party! In *Blog, Free as mobile gis can be: Unofficial Version of gvSIG Mobile for OpenMoko and Nokia-Maemo*
[Accessed 07/06/2009]
http://gvsigmobileonopenmoko.wordpress.com/2009/04/06/sqlite-nokia-join-the-party/

RUGGLES, CLIVE (1993) *Archaeoastronomy in the 1990s*, United Kingdom, Loughborough, Leicestershire: Group D Publications Ltd, ISBN 1-874152-01-2

SCARRE, CHRISTOPHER and FAGAN, BRIAN M. (2003) *Ancient Civilisations*, United States of America: Prentice Hall, ISBN 0130484849

SCHIFFER, MICHAEL BRIAN (2000) Social Theory in Archaeology: Building Bridges, in *Social Theory in Archaeology*, Edited by Schiffer, Michael Brian, Chapter I, United States of America, Utah, Salt Lake City: University of Utah Press, ISBN 0-87480-642-9

SCHOYEN, MARTIN (2007) The Schoyen Collection MS 2645, in *The Schoyen Collection*, Norway and United Kingdom, Oslo and London: The Schoyen Collection http://www.nb.no/baser/schoyen/4/4.4/441.html2645

SCHULDENREIN,JOSEPH, WRIGHT, RITA P. , MUGHAL, M. RAFIQUE and KHAN, M. AFZAL (2004) Landscapes, soils, and mound histories of the Upper Indus Valley, Pakistan: new insights on the Holocene environments near ancient Harappa, in the *Journal of Archaeological Science*, Volume 31, Issue 6, June 2004, Pages 777-797
[Accessed 19/06/2007]
ScienceDirect.com

SCIENCE DIRECT (2009) *Science Direct*, United States of America
[Accesed 20/06/2009]
http://www.sciencedirect.com

SEGALLER, STEPHEN (1999) *Nerds 2.0.1: A Brief History of The Internet*, United States of America, New York: TV Books, L.L.C., ISBN 1575000881.

SHADY, R. (2001) *Caral: Oldest City in the New World,* a conversation with Dr. Ruth Shady, excerpt of part of a television documentary programme broadcast on The Archaeology Channel
[Accessed 06/12/2005]
http://www.archaeologychannel.org/caralint.html

SHADY, R., HAAS, J. and CREAMER, W. (2001) Dating Caral, a Preceramic Site in the Supe Valley on the Central Coast of Peru, *Science*, 27 April 2001: Vol. 292. no. 5517, pp. 723 - 726

SHAFER, DAN (1987) *Turbo Prolog Primer*, p.4, United States of America: Howard Sams and Company, ISBN 0-672-22615-4

SHAFFER, J.G. and LICHTENSTEIN (2005) South Asian Archaeology and the Myth of Indo-Aryan Invasions, in *The Indo-Aryan Controversy*, Editor Bryant, Edwin F. and Paterrn, Laurie L., 2005, United Kingdom, Oxford: Routledge, ISBN 0-700-71462-6

SHARMA, R. S. (2000) Problems of Continuity and Interaction in Indus and Post-Indus Cultures, in the *Social Scientist*, Vol. 28, No. 1/2 (Jan. - Feb., 2000), pp. 3-11, Social Scientist
[Accessed 15/06/2009]
http://www.jstor.org/stable/3518054

SHARMA, R. S. (2002) Rg Vedic and Harappan Cultures: Lexical and Archaeological Aspects, in the *Social Scientist*, Vol. 30, No. 7/8 (Jul. - Aug., 2002), pp. 3-12, Social Scientist
[Accessed 06/06/2009]
http://www.jstor.org/stable/3518148

SHENNAN, S. (1988) Statistics, in *Archaeology: An Introduction Edition: The History, Principles and Methods of Modern Arcaheology*, Third Fully Revised, by Kevin Greene, 1995 United Kingdom, London: Taylor and Francis Group, Routledge, ISBN 0-203-75544-8

SHERRATT, ANDREW (1980) Water, Soil and Seasonality in Early Cereal Cultivation, in *World Archaeology*, Vol. 11, No. 3, Water Management (Feb., 1980), pp. 313-330, United Kingdom, London: Taylor & Francis Ltd
[Accessed 15/06/2009]
http://www.jstor.org/stable/124253

SHUKLA, KRIPA SHANKAR (1987) Main Characteristics and Achievements of Ancient Astronomy in Historical Perspective, in *History of Oriental Astronomy: Proceedings of the International Astronomical Union*, Colloquium No. 91 in New Delhi, India on 13-16 November 1985, A transcription of an invited talk, United Kingdom, Cambridge: Cambridge University Press, ISBN 0-521-34659-2

SISK, MATHEW L. (2007) *Student Web Page*, United States of America, New York: Stoney Brook University, Dept. of Anthropology
[Accessed 16/11/2007]
http://gibbon.anat.sunysb.edu/IDPAS/index.php?page=students/sisk

SIVEN, N. (1986) Chinese archaeoastronomy: between two worlds, in *World Archaeoastronomy: Selected papers from the 2nd Oxford International Conference on Archaeoastronomy*, held at Merida, Yucatan, Mexico, 13-17 January 1986, Editor Aveni, A.F., United Kingdom, Cambridge: Cambridge University Press, ISBN 0-521-34180-9

SMITH, ADRIAN F. M. (1991) Bayesian Computational Methods in the *Philosophical Transactions: Physical Sciences and Engineering*, Vol. 337, No. 1647, Complex Stochastic Systems (Dec. 15, 1991), pp. 369-386, United Kingdom, London: The Royal Society
[Accessed 21/06/2009]
http://www.jstor.org/stable/53988

SRINIVASAN, DORIS (1975) The So-Called Proto-śiva Seal from Mohenjo-Daro: An Iconological Assessment, in *Archives of Asian Art*, Vol. 29, (1975/1976), pp. 47-58, United States of America: University of Hawai'i Press for the Asia Society
[Accessed 12/06/2009]
http://www.jstor.org/stable/20062578

SPODEK, HOWARD (1974) Rulers, Merchants and Other Groups in the City-States of Saurashtra, India, around 1800, in *Comparative Studies in Society and History*, Vol. 16, No. 4 (Sep., 1974), pp. 448-470, Cambridge University Press
http://www.jstor.org/stable/178017

STINE, LINDA F. and STINE, ROY A. (1990) GIS, archaeology and freedom of information, in *Interpreting Space: GIS and Archaeology*, by Allen, Kathleen M.S., Stanton, W. Green and Zubrow, Ezra B.W., United States of America, Bristol, PA : Taylor and Francis Inc., ISBN 0-85066-824-7

SWARM (2009) *Swarm Main Page*, United States of America, Michigan: The Center for the Study of Complex Systems at the University of Michigan
[Accessed 23/06/2009]

PROSPECTOR (2006) *Prospector*, School of ECM, University of Surrey, Guildford, Surrey GU2 5XH, United Kingdom
[Accessed 16/06/2006]
http://www.computing.surrey.ac.United Kingdom/AI/PROFILE/prospector.html

TANN, JOHN and FLEMONS, PAUL (2008) Falling Rain, in *The Atlas of Living Australia*, Review of Online and Desktop Tools, Gazetteers, World-wide Gazetteers
[Accessed 29/06/2009]
http://alatools.pbworks.com/Gazetteers

THAKKER, P.S., RAVAL, M.H. and DASGUPTA, A.R. (2000) Ancient ports of Gujarat, *gisdevelopment.net*, Geospatial Application Papers: Archaeology: Site Prediction, February
[Accessed 01/06/2005]
http://www.gisdevelopment.net/application/archaeology/site/archs0004.htm

THAPAR, ROMILA (1983) The Dravidian Hypothesis for the Identification of Meluhha, Dilmun and Makan, in *The Journal of Economic and Social History of the Orient*, Vol. 26, No. 2, pp.178-190, BRILL
[Accessed 29/01/2009]
http://www.jstor.org/stable/3631801

THEODORIDIS, SERGIOS and KOUTROUMBAS, KONSTANTINOS (2006) *Pattern Recognition*, Third Edition, United States of America, California, San Diego: Academic Press, ISBN 0-12-369531-7

THEUNISSEN, ROBERT, GRAVE, PETER AND BAILEY, GRAHAME (2000) Doubts on Diffusion: Challenging the Assumed Indian Origin of Iron Age Agate and Carnelian Beads in Southeast Asia, in *World Archaeology*, Vol. 32, No. 1, Archaeology in Southeast Asia (Jun., 2000), pp. 84-105, United Kingdom, London: Taylor and Francis Ltd
[15/06/2009]
http://www.jstor.org/stable/125048

THOMAS, KEIR (2007) *Beginning Ubuntu Linux*, Second Edition, United States of America, New York: Springer-Verlag, ISBN 978-1-59059-820-7

TYLER, ALAN (2005a) High levels of lead in Harappan tools, *Conversation with Dr. A. Tyler*, curator of Bromley Museum (Retired), Friday 09/12/2005 c.20.00, United Kingdom, Kent, Orpington

TYLER, ALAN (2005b) Evidence Harappan trade in Mesopotamia, *Conversation with Dr. A. Tyler*, curator of Bromley Museum (Retired), Friday 09/12/2005 c.20.00, United Kingdom, Kent, Orpington

TYLER, ALAN (2005c) Fortification as a sign of wealth, *conversation with Dr. A. Tyler*, curator of Bromley Museum (Retired.), Friday 09/12/2005 c.20.00, United Kingdom, Kent, Orpington

TYLER, ALAN (2006) Small Ports Project: identifying suitable boat beaching/building/breaking sites, *e-mail correspondence with Dr. A. Tyler*, curator of Bromley Museum (Retired.), United Kingdom, Kent, Orpington

ULLMAN, EDWARD (1941) A Theory of Location for Cities, in *The American Journal of Sociology*, Vol. 46, No. 6 (May, 1941), pp. 853-864, United States of America: The University of Chicago Press
[Accessed 09/07/2009]
http://www.jstor.org/stable/2769394

UNITED STATES ARMY MAP SERVICE (1955) *India and Pakistan 1:250,000*, United States of America, Washington: The United States Army Map Service
[Accessed 17/05/2005]
http://www.lib.berkeley.edu/EART/india/250k.html

VAN DALEN, J. (1999) Probability modelling: a Bayesian and a geometric example, in *Geographical Information Systems and Landscape Archaeology*, by Gillings, M., Mattingly, D., and van Dalen, J. (eds.) United Kingdom, Oxford: Oxbow Books, Park End Place

VAN LEUSEN, MARTIJN AND KAMERMANS, HANS (Editor) (2005) *Predictive Modelling for Archaeological Heritage Management: A Research Agenda*, Chapter 11, Netherlands, Amersfoort:National Service for Archaeological Heritage, ISBN 90-5799-060-1

WALL, CARA M. and WALL, ZACHARY R. (2006) Focus: A Technical Note, Research Design in Digital Luminance Analysis, in the *Journal of Archaeological Science*, 33 (2006) 1152-1156, Netherlands, Amersterdam: Elsevier Inc., ISSN 0305-4403
[Accessed 07/06/2009]
http://dx.doi.org/10.1016/j.jas.2005.12.002

WALLERSTEIN, IMMANUEL (1995) *Historical Capitalism with Capitalist Civilization*, United Kingdom, London: Verso, ISBN 1-85994-105-8

WARMINGTON, E.H. (1974) *The Commerce Between the Roman Empire and India*, Pt I, Chapter I The Trade Routes Between Rome and India: Egypt and the Sea-Route to India, pages 1-15, United Kingdom, London: Curzon Press, ISBN 0 7007 0037 4

WARREN, ROBERT E. and ASCH, DAVID L. (2000) A Predictive Model of Archaeological Site Location in the Eastern Prairie Peninsula, GIS Applications in Archaeology: Method in Search of Theory, in *Practical Applications of GIS for Archaeologists: A Predictive Modeling Toolkit*, edited by Wescott, Konnie L and Brandon, Joe R., Chapter 10, United Kingdom, London: Taylor and Francis, ISBN 0-203-21213-4

WEATHER UNDERGROUND (2009) *Internet Weather Service*, United States of America, Michigan,:Weather Underground Inc.
[Accessed 02/02/2009]
http://www.wundergound.com

WEATHERBASE (2009) *Ahmadabad Weather Records*, USA, Virginia: Canty and Associates LLC
[Accessed 28/01/2009]
http://www.weatherbase.com/weather/weather.php3?s=74624&refer=

WEAVER, MARTIN (1966) Great Bath Axonometric Reconstruction, in *Civilisations of The Indus Valley and Beyond*, by R.E.M Wheeler, p.16, United Kingdom, London: Thames and Hudson

WEBER, STEVEN A. (2003) Archaeobotany at Harappa: Indications for change, in *Indus Ethnobiology: New Perspectives from the Field*, Editor Weber, Steven A. and Belcher, William R., United States of America, Maryland: Lexington Books. ISBN 0-7391-0609-0

WEISS, HARVEY, COURTY, M.-A, WETTERSTROM, W. , GUICHARD, F., SENIOR L. , MEADOW, R. and CURNOW, A. (1993) The Genesis and Collapse of Third Millennium North Mesopotamian Civilization, in *Science*, New Series, Vol. 261, No. 5124 (Aug. 20, 1993), pp. 995-1004, United States of America: American Association for the Advancement of Science
[15/06/2009]
http://www.jstor.org/stable/2881847

WEISS, HARVEY and BRADLEY, RAYMOND S. (2001) What Drives Societal Collapse? In *Science*, New Series, Vol. 291, No. 5504 (Jan. 26, 2001), pp. 609-610, United States of America: American Association for the Advancement of Science
[15/06/2009]
http://www.jstor.org/stable/3082228

WESTCOTT, KONNIE L. and BRANDON, R. JOE (Editor)(2000) *Practical Applications of GIS for Archaeologists*, Chapter One, Introduction, p.1, United Kingdom, London: Taylor and Francis Ltd., ISBN 0-7484-0830-4

WHEATLEY, DAVID (2004) Making space for an archaeology of place, in *Internet Archaeology*, Submitted: October 2003; Published: January 2004, United Kindgom, York: Department of Archaeology at the University of York, published by the Council for British Archaeology
[Accessed 05/06/2009]
http://intarch.ac.uk/journal/issue15/10/toc.html

WHEELER, MORTIMER (1955) *Rome Beyond the Imperial Frontiers*, Part Three: Asia, Chapter Nine, The Periplus, p.141, Great Britain: Pelican Books

WHEELER, MORTIMER (1966) *Civilisations of The Indus Valley and Beyond*, United Kingdom, London: Thames and Hudson.

WHITE, ANDREW MARSHALL (2002) *Archaeological Predictive Modeling of Site Location Through Time: An Example from the Tucson Basin*, Arizona, MSc Thesis, August, 2002, Canada, Alberta, Calgary: Department Of Geography, University of Calgary
[Accessed 24/08/2007].
http://www.ucalgary.ca/~amwhit/Thesis/

WHITEHOUSE, RUTH (1977) *First Cities*, United Kingdom, Oxford: Phaidon Press Ltd., ISBN 0-7148-1678-7

WHITTAKER, C.R. Do Theories of the Ancient City Matter? In *Urban Society in Roman Italy*, By Cornell, T.J. and Lomas, Kathryn (Editor), United Kingdom, London: University College London Press Ltd., ISBN 1-85728-033-4.

WHITTLESEY, JULIAN H. (1974) *Aerial Archaeology: A Personal Account, Journal of Field Archaeology*, Vol 1 of 2, United States of America: Boston University for the Association of Field Archaeology
[Accessed 10/10/005]
http://www.jstor.org/stable/529714

WOODMAN, PATRICIA E. and WOODWARD, MARK (2002) The use and abuse of statistical methods in archaeological predictive modelling, in *Contemporay Themes in Archaeological Computing*, Chapter 4, p.22-27, (Editor) Wheatley, David et al, United Kingdom, Oxford: Oxbow Books, ISBN 1-84217-053-8

YOUNG, GARY K. (2001) *Rome's Eastern Trade: International Commerce and Imperial Policy, 31 BC-AD 305*, Chapter, The Red Sea and Egypt, The Trade with India, p.28, United Kingdom, London: Routledge, ISBN 0-415-24219-3

ZADORA-RIO, ELIZABETH (1988) Case Study no.5: The identification of a medieval construction, in *Artificial Intelligence and Expert Systems: Case Studies in the Domain of Archaeology*, by Gardin, Jean-Claude, Ellis Horwood Series in Artificial Intelligence Foundations and Concepts, United Kingdom, England, Sussex: Ellis Horwood Ltd., ISBN 0-7458-0431-4

About this Document

Author:	Roy Mathur, Archaeology Dept., UniversityYork, UK
Title:	Predictive Modelling of Harappan Port Sites in The Gujarat
File Name:	rmathuryork.doc
Page Count:	424
Words Count:	Approx. 89,876
Font:	Times New Roman